ALL OUT OF PROPORTION? Stature and Body Proportions in Roman and Early Medieval England

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Stature and Body Proportions in Roman and Early Medieval England

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Abstract:

The transitional period between the Roman occupation of Britain and the creation of smaller kingdoms during the Early Medieval period is one that is heavily debated. The shift in material culture from the fifth century onwards suggests Continental influences, but the extent to which this represents large-scale migrations or acculturation by indigenous people is contested. New bioarchaeological and isotopic studies of skeletal remains demonstrate an improvement in health from the Roman to Early Medieval periods, along with greater evidence of a much more complicated picture with respect to the direct association of particular grave goods with migrants. This comprehensive analysis of stature, body proportions, and health stress from the Romano-British to Early Medieval period represents an additional bioarchaeological contribution to these debates.

A total of 1248 individuals excavated from 20 cemetery sites of Romano-British and Early Medieval date throughout southern and eastern England were analysed. Stature was examined as an indicator of health and growth as it is associated with childhood adversity, whilst body proportions can reflect adaptations to local environments. The stature and body proportions of individuals from all sites were determined through the reconstruction of living stature using Raxter *et al.*'s (2006, 2007) revised Fully anatomical method and through the analysis of a variety of indices. New mathematical regression formulae were created for each sample based on the reconstructed living stature. Comparisons of the anatomical and mathematical methods of stature calculation discovered a general overestimation of stature when the Trotter and Gleser, 1952, 1958 and Trotter, 1970 methods were used.

The use of different indices aided in the assessment of examining differential body proportions within and between periods. In combination with the skeletal indicators of stress recorded, shorter tibial lengths, lower crural and higher intermembral indices, and shortened relative lower limb lengths demonstrated the negative impact that Roman occupation had on the residents of Britain. An improvement in overall health was noted within the Early Medieval sample with a decreased prevalence of these stress indicators, as well as increases in indices and stature. This thesis demonstrates the usefulness of utilizing the anatomical method when estimating stature of past populations in conjunction with the analysis of body proportions and stress indicators.

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Illustration on cover courtesy of Naomi Bobbie Louise Brannan

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Statement of Copyright

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For Mom and Dad

Chapter One: Introduction

Adult stature is the product of the dynamic relationship between environmental stress and genetic potential in a population (Tanner, 1990; Bogin, 1999). Since the 1980s, economists, historians, and biological anthropologists have worked together to reconstruct life experiences of past populations, specifically citing stature as a measurable way to determine biological living standards (Steckel *et al.*, 2002) and social class distinctions (Kunitz, 1987). Despite a variety of studies focusing on diverse populations, such as American slaves (Steckel, 2007), ancient and modern Korean populations (Shin *et al.*, 2012), and a plethora of studies within medieval and post-medieval Europe (Kunitz, 1987; Steegmann, 1985; Steckel and Floud, 1997; Steckel, 2001, 2004; Roberts and Cox, 2007), few have focused on the transition between Roman and Early Medieval Britain. This thesis aims to critically assess the reliability of current methods of estimating stature for Romano-British and Early Medieval populations and will create new population specific regression formulae. It also assesses differences in body proportions, skeletal indices, and evidence of childhood adversity both within and between these two periods as indicators of health and population continuity or change.

1.1 Stature and Body Proportions

Currently, the most widely utilised regression formulae for estimating stature of bioarchaeological populations in the United Kingdom are those developed by Trotter and Gleser (1952, 1958) and Trotter (1970). Thus, the stature of past populations have been estimated with reference to those who are genetically, geographically and temporally far removed. Many researchers (Sciulli and Hetland, 2007; Giannecchini and Moggi-Cecchi, 2008) have expressed the importance of applying population appropriate mathematical regression formulae to the population being studied due to differences in body proportions throughout the world. Through the years, new formulae have been created for specific populations to better estimate living stature, taking differences in body proportions into consideration. For example, new formulae have been created for North American Ohio Native Americans (Sciulli *et al.*, 1990), Ancient Egyptians (Raxter *et al.*, 2008), Pre-hispanic populations in Chilé (Béguelin, 2011), ancient Korean populations (Shin *et al.*, 2012), and Medieval populations within the Czech Republic (Sládek *et al.*, 2015).

Stature in bioarchaeology is assessed through the measurement of long bones and skeletal elements directly related to stature. Interest in exploring the relationship between long bone lengths and overall stature began in the late 19th century. These original studies are still utilized today in calculating stature from human skeletal elements (e.g. Pearson, 1899). Stature is calculated one of two ways: through the measurement of all skeletal elements directly related to an individual's height or through the measurement of one or two long bones and the use of mathematical regression formulae derived from reference populations. As preservation of human skeletal remains varies, it is difficult for bioarchaeologists to measure all skeletal elements, thus stature calculated from mathematical regression formulae tends to be the most widely used. Due to the variation in reported stature produced from different mathematical regression equations, a recent study by Goldewijk and Jacobs (2013) concluded that a direct comparison of long bone lengths, rather than estimated stature, between populations is likely to be a better index of health. This belief was also held by Brothwell and Zakrzewski (2004), in which they state "Any data analysis should therefore concentrate upon using the raw long bone lengths rather than predicted statures (with their associated errors)" (pg. 33). Long bones are more sensitive to environmental stressors and by extension, standard of living. Proponents of assessing standard of living through the analysis of long bone lengths state that stature estimation is just that, an estimate, and that there are associated errors when predicting stature from skeletal remains (Brothwell and Zakrzweski, 2004: 33). However, studies that compare only long bone lengths fail to address the area of the body where the majority of organs rest, the torso. Such studies, if comparing only a single long bone between populations, will also fail to detect differences in body proportions. It is therefore informative to consider the skeleton as a whole when possible. Studies of both body proportions and stature are beneficial to bioarchaeologists, especially when they are used in conjunction with various lines of study such as stable isotope analysis from human tissues (diet, mobility, and climate) and pathological studies at the population level.

The body shape, size, and proportions of humans tend to follow an ecogeographic pattern (Trinkaus, 1981; Ruff, 1994; Holliday, 1997a,b; Auerbach and Ruff, 2010, Auerbach, 2012). These variations are caused by differences in the need for thermoregulation by mammals residing in different climates. The shortening and elongation of different long bones are part of the ecogeographic variation (Auerbach, 2012; Ruff *et al.*, 2012) and are a way for the body to adapt to local environment (Johnston, 1998b; Temple, 2011). Specifically, variations in the length of the tibia in different populations has been of interest to researchers. These variations have been discovered to occur with changing latitudes (Ruff, 2002) and in populations experiencing improved environmental conditions and nutrition (Eveleth and Tanner, 1990; Ruff, 1994; Norgan, 1998; Pomeroy *et al.*, 2012). In Ruff *et al.*'s (2012) study of body proportions in Europe, it was noted that populations residing in southern regions tended to possess longer tibiae than populations from the north. These changes in body proportions might provide greater insight not only with regard to ecogeographic variation, but the impact of environmental stress on the growth and development of different areas of the body. These differences in body proportions could also help researchers assess childhood adversity (Gowland, 2015), although such studies have rarely been used in bioarchaeology to date.

1.2 Research Aims

This research aims to determine the efficacy of frequently utilised regression formulae for estimating stature from Romano-British and Early Medieval human skeletal remains. In order to do so, stature is calculated employing the Fully anatomical method. The Fully calculated stature will be used as a 'known' living stature. It is recognized that this calculation is not the actual stature of an individual, but only an estimate based on soft tissue corrections applied to skeletal height. However, numerous studies (Raxter *et al.*, 2008; Vercellotti *et al,* 2009; Auerbach and Ruff, 2010; Béguelin, 2011; Sládek *et al.*, 2015) have utilized the revised Fully anatomical method (Raxter *et al.*, 2006, 2007) to assess stature and create new population-specific mathematical regression formulae to estimate stature from long bone lengths. New regression formulae specific for the Romano-British and Early Medieval populations will be created using this method as many peer-reviewed articles have done previously. The role of differing body proportions in the construction of stature is examined. The assessment of overall health through the comparison of long bone lengths rather than stature (as recommended by Brothwell and Zakrzewski (2004) and Goldewijk and Jacobs (2013)) will be addressed. The combined analysis of stature and body proportions along with skeletal indicators of stress aims to contribute to debates concerning the increase in stature and putative improvement in health between these two periods and the possible causes, i.e. whether it is due to migration, or environmental change.

1.3 Research Objectives

In order to achieve these aims this study has seven primary objectives:

1. Measure and record all skeletal elements constituting stature and calculate stature using the revised Fully anatomical method recommended by Raxter *et al.* (2006, 2007) from as many individuals as preservation allows from Romano-British and Early Medieval skeletal samples. These measurements include cranial height, maximum vertebral body heights from C2 thru L5, the first sacral body height, physiological/bicondylar femoral length, tibial length (from the lateral condyle to the medial malleolous, not including the intercondylar eminence), and the articulated height of the talus and calcaneus.
2. Following Auerbach (2011), create formulae for calculating missing vertebral elements (adjacent vertebrae and vertebral sections) to allow for a greater number of individuals to have stature estimated using the revised Fully anatomical method.
3. Using the revised Fully anatomical estimates as a proxy for 'known' stature, create population specific regression formulae to estimate living stature in Romano-British and Early Medieval populations in England as previously published studies have done.
4. Assess the reliability and accuracy of regression formulae most commonly used to predict living stature in these populations through a comparison of stature calculated using these formulae to the 'known' (Fully anatomical) stature. This will be accomplished through the use of *t*-tests or Mann-Whitney tests (dependent on whether data is normally distributed).
5. Examine body proportions of Roman and Early Medieval samples through the use of brachial, crural, intermembral, humerofemoral, and brachiocrural indices along with absolute skeletal trunk height, relative lower limb length, relative upper limb length and torso height, and finally relative torso height.
6. Compare differences in body proportions within skeletal samples (e.g. sex, age, and inter-site differences) and between periods. These will also be compared

statistically through the use of parametric (*t*-tests) or non-parametric (Mann-Whitney) tests.

7. Record skeletal indicators of stress (cribra orbitalia, dental enamel hypoplasia, periosteal new bone formation, and residual rickets) to aid in the assessment of stress during early childhood development and possible impacts seen in adult stature and body proportions.

8. Assess whether the current recommended trend of comparing long bone lengths rather than the estimation of stature between past populations is the most reliable index of health, rather than overall body proportions and stature.

1.4 Research Questions

1. Which commonly used regression formulae for estimating stature (Pearson, 1899; Breitinger, 1937; Dupertuis and Hadden, 1951; Trotter and Gleser, 1952, 1958; Allbrook, 1961; Bach, 1965; Trotter, 1970; Olivier *et al.*, 1978; Černy and Komenda, 1982; Ross and Konigsberg, 2002; Hauser *et al.*, 2005; Vercellotti *et al.*, 2009) is most accurate in predicting living stature in Roman and Early Medieval populations throughout the south and east of England?
2. Will population specific regression formulae created from reconstructed living stature of Romano-British and Early Medieval individuals be more accurate in predicting living stature than regression formulae used in the current literature?
3. Will individuals dating to the Romano-British and Early Medieval periods present different body proportions? If there is a difference in body proportions between these two populations, in which aspect of the body does this occur, e.g. lower or upper limbs, distal segments of limbs (radius and tibia), or vertebral column?
4. Will there be differences between males and females with regards to stature and/or body proportion indicating differences in general health, nutritional resources, mobility, and response to climatic environment? What can this indicate about growth and development during these two periods?
5. Is there a decrease in the prevalence of stress indicators between the Romano-British and Early Medieval periods that corresponds with stature change between these two periods?

6. Are there any geographical and/or temporal trends in stature, body proportion, and sexual dimorphism between these periods?
7. What potential information may be lost through the analysis of long bone lengths alone when assessing temporal trends in stature?

1.5 Thesis Outline

In order to address the research aims and questions provided in Sections 1.2 and 1.4, the structure of this thesis will take the following outline:

Chapter Two: Human Growth and Development- This chapter will present a brief background on the history of the study of human growth and development from the ancient Greeks to modern day research on living populations. It provides essential information on the growth of humans, including intrauterine growth, the rapid growth period experienced during infancy, the mid-growth spurt during childhood development, the accelerated growth during adolescence, and the final adult form. Finally, this chapter analyses the impact of environmental stress experienced within the intrauterine and post-natal environments on growth and final adult stature. Developmental plasticity is explored with regard to three hypotheses (Developmental Origins of Health and Disease, predictive adaptive response, and the intergenerational influence hypothesis) on the impact of early life stressors.

Chapter Three: Stature and Body Proportions- This chapter contains a review of the current literature on bioarchaeological and modern studies of stature and body proportions. It begins with an overview relating the importance of the study of stature to various disciplines, as well as information about the historical background including the origins and development of frequently cited stature regression formulae. Reference populations used in regression formulae will become important when discussing appropriateness of certain formulae to the Romano-British and Early Medieval samples. Descriptions of ecogeographic variations in body proportions (Bergmann's and Allen's rules) is provided. Numerous studies from varying geographic and temporal periods applying the methods of assessing health or variation using stature and body proportion analysis are examined.

Chapter Four: Materials- Background information from all sites analysed within this thesis will be provided within the materials chapter. This includes historical background and context for each archaeological site, the number of inhumations excavated at each of the 20 sites, and the number of individuals from each site recorded.

Chapter Five: Methods- Within this chapter, sex and age estimation criteria, all measurements taken from the cranium, long bones, vertebrae, and articulated calcaneus and talus are described; methods employed to estimate missing individual vertebral body heights and missing cervical and thoracic vertebral sections will be discussed; the revised Fully anatomical and mathematical methods used to calculate stature will be outlined; and finally, calculations of all indices and relative body proportions will be presented. Along with stature and body proportion estimates, methods of assessing non-specific skeletal indicators of stress (NSIS) (cribra orbitalia, residual rickets, dental enamel hypoplasia, and periosteal new bone formation) are illustrated. Included within this chapter is a brief critique on the methodological issues of using published and unpublished osteology reports.

Chapter Six: Results- This chapter presents a comprehensive analysis of the samples across sex, age, geography, and period. It provides information on the sex and age composition of the sample analysed in section 6.2 and provides frequencies and statistical analyses on the stress indicators recorded in the sample (section 6.3). The accuracy of estimating missing vertebral elements and sections using ‘k-coefficients’ and estimated vertebral sections from published regression formulae will be compared in section 6.4. Estimation of stature using the revised Fully anatomical method will be presented along with new population specific regression formulae in section 6.4. Within the same section comparisons of frequently cited regression formulae used for Romano-British and Early Medieval samples and Fully anatomical stature estimation will be made. Finally, the assessment of long bone lengths and the nine indices/relative lengths to analyse body proportions will be investigated within and between both periods (section 6.5).

Chapter Seven: Discussion- This chapter will explore the implications of inaccurate stature estimation and varying body proportions within and between the two periods analysed. Detailed investigations of the regression formulae from Trotter and Gleser (1952, 1958), Trotter (1970), and the population specific formulae from this thesis will be conducted for females and males with an examination of the role of body proportions on the construction of adult stature. Body proportions from these samples will be placed into a global context through the comparison of indices from human skeletal remains analysed throughout North America, South America, Africa, and Europe. Finally, the results of stature and body proportion analysis will be discussed in the contexts of Romano-British and Early Medieval Britain.

Chapter Eight: Conclusion-This chapter will summarise and conclude this thesis. It will assess each research question and provide suggestions for future research.

Chapter Nine: Bibliography

Chapter Two: Human Growth and Development

Early life stressors can have a drastic impact on the adult form, therefore a study of stature and body proportions must first consider how the body develops from the intrauterine environment through to adulthood. The aim of this chapter is to provide a brief background on the study of human growth and development and provide insight regarding the various stages of development and their potential impacts on skeletal growth. The first section presents a summary of the history and study of growth and development (section 2.1). This is followed by descriptions of major stages in the growth process for humans (section 2.2). Finally, the last section (section 2.3) explains three hypotheses of the impact of intrauterine environment on adult health and the effects of improved nutrition and environmental surroundings giving the body the ability to 'catch-up' in growth.

2.1 Early studies of human growth and development

The study of the human body and its proportions has roots in art as well as science (Harrison, 1990; Steckel, 2008). Anthropometry, the measurement of physical characteristics in humans (Norgan, 1994:141), was "born not of medicine or science, but of the arts, impregnated by the spirit of Pythagorean philosophy" (Tanner, 1981:32). Observations of growth and development in the human body have been noted for centuries, from the Greeks to modern social scientists and biologists (Voss, 2001). The earliest statement dividing life into different stages was a poem by Solon, a Greek statesman and lawmaker (Tanner, 1981:1-2). In his poem, a man's life is divided into ten separate '*hebdomads*' each consisting of seven years, the earliest of which are predicated on the physical changes experienced during growth and development (Tanner, 1981). It is in these earliest stages that Aristotle noted that humans reach approximately half of their final height (by approximately 5 years of age); an opinion that modern day studies tend to support (Tanner, 1981:8). These observations came to a halt during the medieval period with the depiction of children as 'little adults' and during which time there was less interest in the physiological development of children (Voss, 2001). Though depictions of children during the Renaissance period become more childlike, there was still very little focus on the physical growth and development of humans (Voss, 2001:5).

One of the first scientific studies of human growth was reported more than 230 years ago with the longitudinal growth study of the son of Compte de Montbiellard (Tanner, 1981; Bogin, 1999; Voss, 2001; Pinhasi *et al.*, 2011) published as the first growth chart in Buffon's (1777) *Histoire Naturelle* (Cole, 2012). Measurements of the Compte's son were taken in six month intervals between infancy and adulthood (AD 1759 and 1777), producing the first height growth curve (Tanner, 1962) (Fig. 2.1). The plotted growth in stature demonstrated periods of accelerated growth during infancy and childhood, followed by a growth spurt during the pubertal or adolescent period (Tanner, 1981; Bogin, 1999). Following this publication in the 18th century, interest increased in the growth of humans, particularly newborns, with doctors taking a multitude of measurements of infants (Voss, 2001:7). It was not until the 19th century that more scientific investigations of human growth began with the use of various anthropometric measurements aligning human growth to the environment (Voss, 2001; Wilson, 2001:6492). A particular focus of this research was the link between child labour, health, and final adult height. In AD 1829, Villermé analysed the stature of French and Dutch soldiers, concluding that poverty had a greater influence on human growth than the climate (Steckel, 1995). Prompted by Villermé's study, Edwin Chadwick investigated the health of England's factory children through the measurement of their heights (Steckel, 1995:1907). Chadwick (1842) noted that factory children were not reaching their previous generation's average height. He attributed this to poor sanitary conditions seen in factories and mines throughout England in the early 19th century (Chadwick, 1842). The significant decrease in the

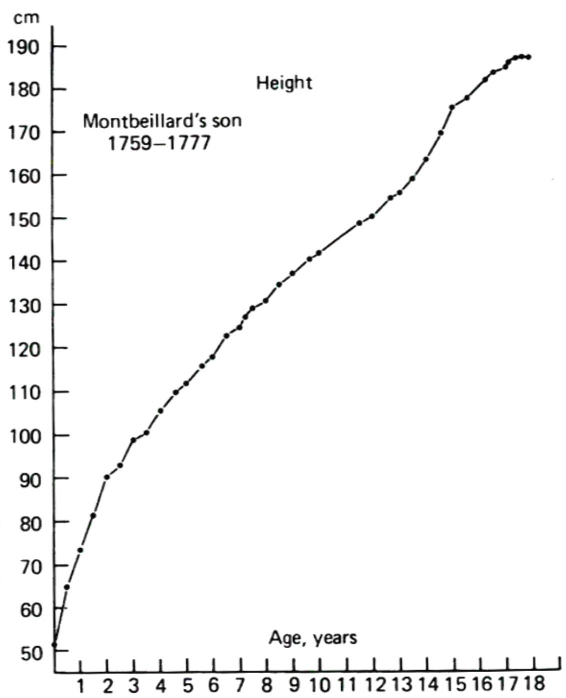


Figure 2.1: *First height growth curve created through measurements of six month intervals of Compte de Montbiellard's son between AD 1759 and 1777. Source: Tanner, 1981 p. 104.*

stature of the poor during the industrial revolution contributed to social reform, which limited the number of working hours for factory children and advocated more physical activity during school (Voss, 2001:9-10). Table 2.1 illustrates the average heights of ten and 18 year old males from AD 1833, compared to those in AD 1989.

Table 2.1: *Comparison of mean height of ten and 18 year old males from AD 1833 and AD 1989. Source: Tanner, 1989 pg. 158.*

	Average Height in AD 1833	**Average Height in AD 1989**
Child (10 year old male)	121 cm	160 cm
Adult (18 year old male)	140 cm	175 cm

Other well-known researchers in the field of human growth and development during the 19th and early 20th centuries include Charles Roberts, Henry Bowditch and Franz Boas (Steckel, 2008). Between AD 1872 and 1873, Roberts analysed the fitness levels of factory workers in England by measuring stature, weight-for-stature, and chest circumference (Tanner, 1981; Steckel, 2008). Bowditch, between the 1870s and 1890s, conducted a longitudinal study of male/female growth, developing growth standards from these studies (Tanner, 1981; Steckel, 2008). Franz Boas was interested in the effects of heredity and environment on the growth of humans and developed national standards for height and weight from previously published studies (Steckel, 2008). It was during this period in the United States that debates over nature versus nurture in the healthy development of children predominated (Voss, 2001). Proponents of nature such as Paul Broca, who ranked humans into superior and inferior categories (Gould, 1997), were concerned that migrants from southern and eastern Europe would negatively affect the physiology of Americans. In contrast to Broca's nature theory, Boas demonstrated that immigrant children born in the United States attained a greater stature than their migrant parents, as a consequence of better health and nutrition, not genetics alone (Voss, 2001:9-10). The phenotypic changes of migrants from Europe travelling to the United States detected in this study demonstrated the plasticity of human development (Tanner, 1981; Ulijaszek, 1998).

During the 20th century, researchers turned the spotlight on longitudinal studies of human growth and development (Voss, 2001). These included the Harvard Growth Study (1922-1934) of children in schools conducted by Dearborn and Shuttleworth

(Voss, 2001:11), the Fels Longitudinal Study beginning in 1929 of individuals living in Ohio (Rolland-Cachera and Péneau, 2011), the Maresh study of healthy middle-class children from Denver, Colorado (Maresh, 1955), the Oxford Child Health Survey (1944-1947) of preschool children in Oxford, England and the Harpenden Growth Study (1948-1971) of children from Hertfordshire, England (Tanner and Cox, 1986:180). These studies took both anthropometric measurements and roentgenographic (radiographic) measurements. The evaluation of growth and development of genetically similar children residing in different environments allowed for the study of the impact of environment on growth trajectories (Steckel, 1995:1910). The impact of body/society interactions on human stature and body proportions can be analysed not only in living populations, but also in past populations using skeletal remains.

One of the first bioarchaeological studies of human growth and development was Johnston's 1962 study of Native American infant and juvenile human skeletal remains from Indian Knoll (Pinhasi *et al.*, 2011). The lengths of six long bones were measured from individuals ageing from foetal to 5.5 years, estimated from the formation and eruption of dentition and ossification centres. These measurements were compared to the roentgenographic measurements from Maresh's (1955) data set. Significant differences were seen in the velocity of growth from all long bones, especially after three years of age, when environmental factors begin to affect genetic growth trajectories (Johnston, 1962:251-252). This study not only noted the difference in velocities between middle-class suburban children and Native American hunter-gatherer infants and juveniles, but also highlighted the decreasing values in two indices (humerofemoral and intermembral) between infancy and 5.5 years of age (Johnston, 1962:253). The humerofemoral index compares the length of the humerus to the length of the femur, whilst the intermembral index compares the summed length of the humerus and radius to the summed lower limb length of the femur and tibia. Growth is constrained by genetics (Steckel, 2008) and adult stature and body proportions are a combination of genetic and environmental influences experienced during childhood (Steckel, 1995; Bogin and Loucky, 1997). The environment can promote or hinder growth and therefore determine whether an individual will reach their full genetic potential in stature (Tanner, 1989; Eveleth and Tanner, 1990).

2.2 Development from foetus to adult

Assessing the development of the human body is essential for providing insight into the life experiences of past populations. Childhood adversity will impact development, including adult stature and body proportions (Goodman and Martin, 2002). Non-adults in cemetery assemblages represent the non-survivors as they have not had the opportunity to recover from the stressors that killed them, whereas adults within a skeletal population are those who survived the growth period (Goodman and Martin, 2002:19). Measurements of human skeletal remains can provide direct evidence of skeletal responses to adaptation to local environments (Goodman and Martin, 2002:19). The study of growth in past populations uses cross-sectional data to assess the changes in dimensions throughout the development of the skeleton (Pinhasi *et al.*, 2014:127) The following section will describe the process of growth and development in humans.

When in an unconstrained environment, the pattern of growth follows a genetic trajectory, known as canalisation (Cameron, 2012:16-18). First described by geneticist C.H. Waddington, growth will proceed as a ball rolling within a canal; when any environmental stress or constraint occurs the ball rolls up the side of the canal slowing the velocity of growth and once this insult has been resolved, the ball rolls back down into the canal picking up velocity, restoring to the original growth trajectory (Cameron, 2012:18-20) (Fig. 2.2). The growth and development of humans follows a similar pattern across different populations; where greatest growth occurs during foetal development and just after birth (Karlberg, 1998; Wilson, 2001; Steckel, 2008), succeeded by a growth spurt seen during adolescence (Wilson, 2001). Though the development of the human body is fairly consistent regardless of geographic locations (Schillaci *et al.*, 2012), the growth and

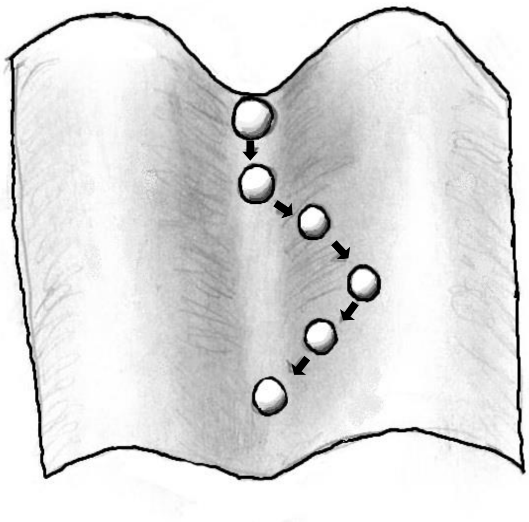


Figure 2.2: *Illustration of canalisation as described by Waddington. By author.*

development of vital tissues and organs within an individual varies in the timing of completion (Cameron, 2012:9). This allows researchers to examine possible disruptions in growth based on asymmetry and proportions of these various tissues and organs (Milani *et al.*, 2000; Cameron and Demerath, 2002:163; Cameron, 2012). Growth curves for stature throughout development should remain similar regardless of variation seen in final stature attained (Lejarraga, 2012:25). Therefore, early life experiences can have a large impact on health and susceptibility in later life (Lejarraga, 2012:40).

2.2.1 Phases of Growth and Development

There are three general periods of post-natal growth in the developing human. Many researchers have attempted to express these periods of growth mathematically to describe the acceleration/deceleration of growth. This thesis will describe Karlberg's mathematical model, referred to as the Infancy, Childhood and Puberty Growth Model, or the ICP Growth Model (Karlberg, 1989, 1998). A fourth period precedes the ICP Growth Model: intrauterine growth (Cameron and Demerath, 2002). Henceforth, puberty will be referred to as adolescence throughout this thesis. Humans are unique in terms of growth and development as the phases of 'childhood' and 'adolescence' are present, and reproductive age is delayed (Bogin, 2012a:290). Patterns in the growth and development of humans are remarkably similar throughout the globe (Karlberg, 1998) (Fig. 2.3). Most growth is controlled by the endocrine system, specifically the hypothalamus, pituitary, and gonadal glands along with other internal organs (Largo, 1999:166; Cameron, 2012). These glands of the endocrine system are known as the HPG axis (hypothalamic-pituitary-gonadal) and are active during foetal, early infancy, and adolescence, not during childhood development (Plant and Barker-Gibb, 2004; Ebling, 2005; Ellison and Reiches, 2012:83-84). The growth hormone is a type of hormone required for normal growth in humans (Tanner, 1989). It releases the insulin-like growth factor-1 (IGF-1), which plays a primary role during foetal and postnatal growth and development (Cameron, 2012:13; Rosenfeld, 2012:119). IGF-1 contributes to the growth in length during infancy and childhood (Cameron, 2012:13). During the period of adolescence, the gonadal gland (greater testosterone in males and greater oestrogen in females) works in conjunction with other growth hormones to promote human development (Cameron, 2012:13). Cessation of growth in stature is initiated by oestrogen through the promotion of mineralization of the growth plates (Ellison and Reiches, 2012).

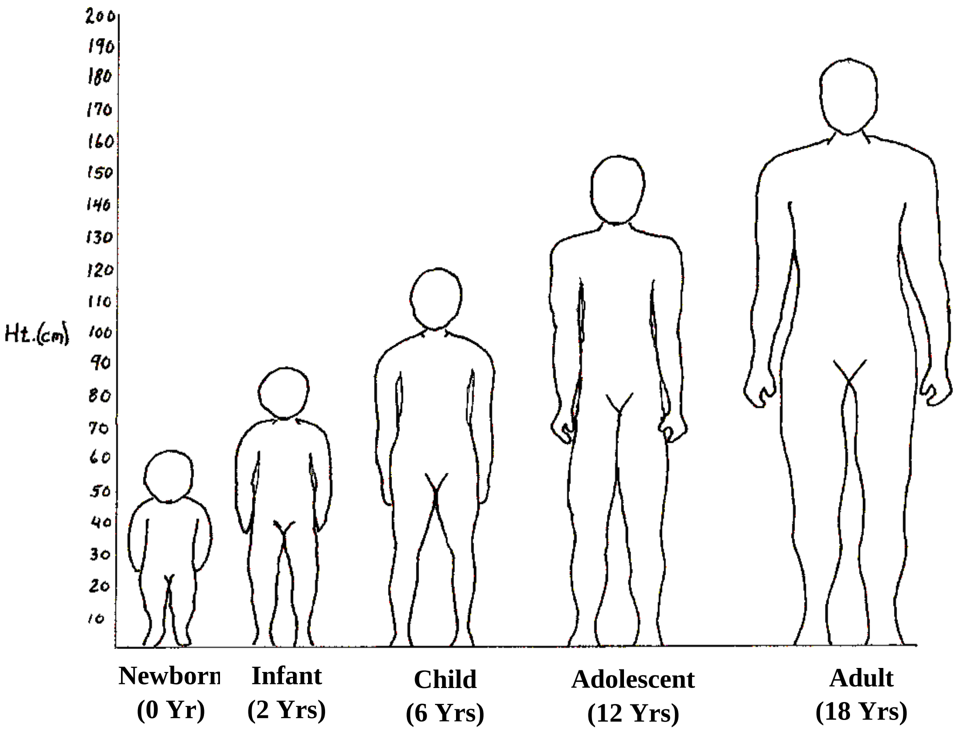


Figure 2.3: *Stature of males throughout the period of growth from infancy through adulthood. Torso height, leg length, and height references from Frederiks* et al.*, 2005. Illustrated by R. Walther.*

2.2.1.1 Intrauterine Development

The growth of the developing foetus is a reflection of the intrauterine environment and maternal size (Lejarraga, 2012). A mother's nutritional intake and body composition can impact the growth of the foetus, especially during rapid periods of growth, potentially impacting the foetus permanently (Barker, 1994; Cameron and Demerath, 2002). Assessing growth and development of the human foetus remains difficult, therefore many studies utilize measurements taken from pre-term infants and ultrasounds *in utero* (Cameron, 2012). Between 20 and 30 weeks of gestational age, a substantial peak in the velocity of growth occurs equating to 120 cm/year, followed by an increase in the amount of weight of a foetus around 30-40 weeks (Cameron, 2012:7-8). This velocity drops after birth (Gasser *et al.*, 1991). The development of the cranium and trunk are most prominent during the first months of pregnancy (known as the crown-rump measurement) (Cameron, 2012:8). Almost 30% of growth in the trunk occurs *in utero*, followed by a sharp decrease in growth after birth (Gasser *et al.*, 1991:191). During the second part of pregnancy, the foetus begins to increase in weight as it prepares for the post-natal environment (Cameron, 2012). This pattern of growth remains the same regardless of the sex of the foetus (Cameron, 2012). Preferential development of the cranium occurs during both foetal and infant development due to the importance of the brain in humans (Bogin, 2012b). The cranium constitutes a quarter of the body length of the foetus, whereas in adults it is only one eighth of the total stature (Tanner, 1989:1; Bogin, 2012b). It is during this period that short term stimuli can have deleterious effects on the health of individuals later in life (Cameron and Demerath, 2002).

2.2.1.2 Infancy

The phase of infant development is defined as the second post-natal month to approximately two years of age; a period when an individual is heavily reliant on the mother for nutritional resources (Bogin, 1999; Cameron and Demerath, 2002; Lejarraga, 2012). It is during these two years that humans develop most rapidly in the post-natal environment, requiring vast amounts of energy to successfully evolve into the adult form (Lejarraga, 2012; Norgan *et al.*, 2012:138). Almost 87% of the resting metabolic rate (RMR) during this period is dedicated to the development of the brain (Bogin, 2012b:351). Vulnerabilities to environmental influences such as malnourishment or infection are at their highest within this growth period (Tanner, 1989; Eveleth and Tanner, 1990; Jantz and Jantz, 1999; Stinson, 2000). When infants do not receive adequate nutrition, delays in growth can occur (Lejarraga, 2012:27). The velocity seen during this phase averages 25 cm/year, with as much as 30 cm/year occurring within the first post-natal year (Lejarraga, 2012:25), followed by a rapid deceleration in the second year (Tanner, 1990; Karlberg, 1998; Lejarraga, 2012:25). A greater amount of sexual dimorphism is seen between four and five months of age as males display higher velocities in growth (Borysławski, 1988:199; Gasser *et al.*, 1991:205). After six months of age, an infant's diet must be supplemented with other nutrients as breast milk will no longer provide adequate nutrition for optimal growth (Lejarraga, 2012). Peak velocity in infant growth generally occurs around seven to twelve months of age (Gasser *et al.*, 1991:187). The area of greatest growth in infancy is the brain (Tanner, 1990; Bogin, 1998) with approximately 85% of its adult size reached within this period (Lejarraga, 2012:32). Alongside the growth of the cranium, the trunk (axial skeletal elements) demonstrates a higher velocity in growth after birth (Werdelin, 1985:187), however, priority is given to the development of the cranium (Tanner, 1990; Gasser *et al.*, 1991; Bogin, 1998). Variation in the measurement of the circumference of the cranium could indicate infant or early childhood stress as this is the period most sensitive to growth disturbances (Tanner, 1989; Prokopec, 2001). From the age of nine months, growth in the lower limbs begin at a steady rate of 1.5% of growth per year until adolescence (Gasser *et al.*, 1991).

With regard to the skeletal development of infants, the development of cranial elements occurs prior to many of the post-cranial elements. By the end of the first post-natal year, the breadth of the frontal bones will have reached 80% of their adult size, whereas, several of the post-cranial elements will only reach 30% of their adult size (Humphrey, 1998:62). Further demonstrating the importance of cranial development in this period, the majority of skeletal elements reaching at least 70% of their eventual adult size include bones of the cranium and most of the mandible (Humphrey, 1998). A greater proportion of the infant body is constructed of axial skeletal elements, with a relatively long trunk in comparison to the rest of the body (Gasser *et al.*, 1991:203). Growth of long bones in the upper (arms) and lower (legs) limbs remains constant throughout a large portion of infant growth until approximately 1.5 years of age when the development of the lower limbs is given priority (Gasser *et al.*, 1991; Cole, 2003; Smith and Buschang, 2005:731). The greatest risk of not reaching genetic potential in adult stature occurs within this period due to the vast amount of growth occurring within the axial skeleton and later in the lower limbs (Lejarraga, 2012).

2.2.1.3 Childhood

For the purpose of this thesis, the period of childhood is defined as between the ages of three and ten years for females and three to twelve years in males (Karlberg, 1998; Smith and Buschang, 2004). This period refers to the slowing deceleration in growth until the adolescent growth spurt (Karlberg, 1998; Bogin, 2012a) and is unique to humans (Humphrey, 1998; Bogin, 2012a). This may have developed from the necessity of learning appropriate behaviour and social norms (Watts, 1986; Leigh, 1996), as well as adaptation to local environments and potential stressors (Bogin, 2012a:303-307), known as developmental plasticity (Kuzawa, 2012:329). A 20% decrease in the velocity of growth is seen between the ages of four and nine years (Smith and Buschang, 2004:653). The slower velocity in growth not only provides time to adapt physically and socially, but also lessens the competition for resources with the adult population (Bogin, 2012a).

Between the ages of one and five, within the deceleration phase and prior to the mid-growth spurt, very little sexual dimorphism is noted with regard to stature (Lejarraga, 2012:26). Though not all individuals within a population will experience a mid-growth spurt (Tanner and Cameron, 1980; Hauspie and Roelants, 2012:58), the timing for it is similar between females and males occurring between six and eight years of age (Bogin, 2012a:297; Lejarraga, 2012:37). The difference between female and male growth during childhood lies in the cessation of this growth spurt, occurring around 7.5 years of age for females and approximately two years later in males (Gasser, 1985; Bogin, 2012a; Lejarraga, 2012:26). The shorter duration of this growth spurt (2.1 years for females versus 2.4 years for males based on the Zürich Longitudinal Growth Study (1955-1976)) and the earlier onset of adolescence in females contributes greatly to the stature difference seen in adulthood (Gasser, 1985; Hauspie and Roelants, 2012). Skeletally, greater velocity within the growth of long bones is seen over growth in the trunk (Gasser *et al.*, 1991:187). Around the age of seven only 44% of the resting metabolic rate is dedicated to the growth and development of the brain. The delay in growth of the long bones is a result of resources being allocated to the development of the brain in the first few years of life (Bogin, 2012b:351). Based on the Zürich Longitudinal Growth Study, peak growth of the trunk during the period of childhood occurs approximately one year prior to the peak velocity seen in long bones, specifically the lower limbs (Gasser *et al.*, 1991:195). The earliest post-cranial skeletal elements to reach 70% of their adult size within the period of childhood include the six long bones of the upper and lower limbs (humerus, radius, ulna, femur, tibia, and fibula) (Humphrey, 1998:63-64). Greater velocity is noted in the lower limbs (femur and tibia) when compared to the upper limb (humerus and radius), whilst greater velocity is seen in the proximal segments (humerus and femur) than distal segments (radius and tibia) (Smith and Buschang, 2004:653).

Growth in the femur occurs mostly on the distal aspect of the bone (Tanner, 1989). Similarly, radial and ulnar growth occurs mostly from the distal ends, whilst the humerus experiences growth near the proximal end (Tanner, 1989). The tibia and fibula are unique and grow equally from both the proximal and distal ends (Tanner, 1989). The lower leg length reaches adult proportions earlier in life than the trunk (Bass *et al.*, 1999; Bradney *et al.*, 2000). The bones in the lower limb become proportionally longer as stature increases, according to a study by Meadows and Jantz (1995). The fusion of epiphyses to the diaphysis of long bones occurs at different times due to differences in the growth rate of cartilage cells (Tanner, 1989). Once fusion occurs growth in the long bones ceases (Tanner, 1990). Later onset of childhood growth will result in reduced time for linear growth in the long bones and perhaps stunted stature, whereas an extended period of childhood growth could result in increased stature (Karlberg, 1998). The childhood period is followed by the rapid acceleration of growth during adolescence (Tanner, 1990; Karlberg, 1998; Wilson, 2001).

2.2.1.4 Adolescence

Definitions of adolescence vary in the literature with some researchers describing puberty as the appearance of secondary sexual characteristics such as breast development, enlargement of genitalia, and pubic hair, whilst others describe it as the activation of the HPG axis (Cameron and Demerath, 2002:161) (see section 2.2.1). Adolescence is generally believed to begin at the onset of puberty (Hauspie and Roelants, 2012) and is likely stimulated not only by growth hormones, but by sex hormones of testosterone (male) and oestrogen (female) (Karlberg, 1998). At the beginning of the adolescent growth spurt, approximately 80% of an individuals' adult height should have been reached (Gasser, 1985:133). This period of growth is second in velocity to the growth experienced in infancy (Norgan *et al.*, 2012:137), averaging 9 cm/year for females and 11 cm/year for males (Hauspie and Roelants, 2012:60) (Fig. 2.4). The adolescent growth spurt is associated with puberty, however it begins prior to the development of breasts in females occurring between 10.5 and 13.5 years (Tanner, 1989, 1990). For males, peak height velocity (PHV) is not reached until after the appearance of secondary sexual characteristics (genitalia enlargement) (Marshall and Tanner, 1970), between 12.5 and 15.5 years of age (Tanner, 1989, 1990). Peak height velocities occur at approximately 12 years of age in females and 14 years of age in males from the United Kingdom (Tanner, 1989:15), three to 3.5 years after the onset of adolescence (Hauspie and Roelants, 2012:60). Towards the end of the PHV, an individual should have reached approximately 91% of their total adult stature (Gasser, 1985:133).

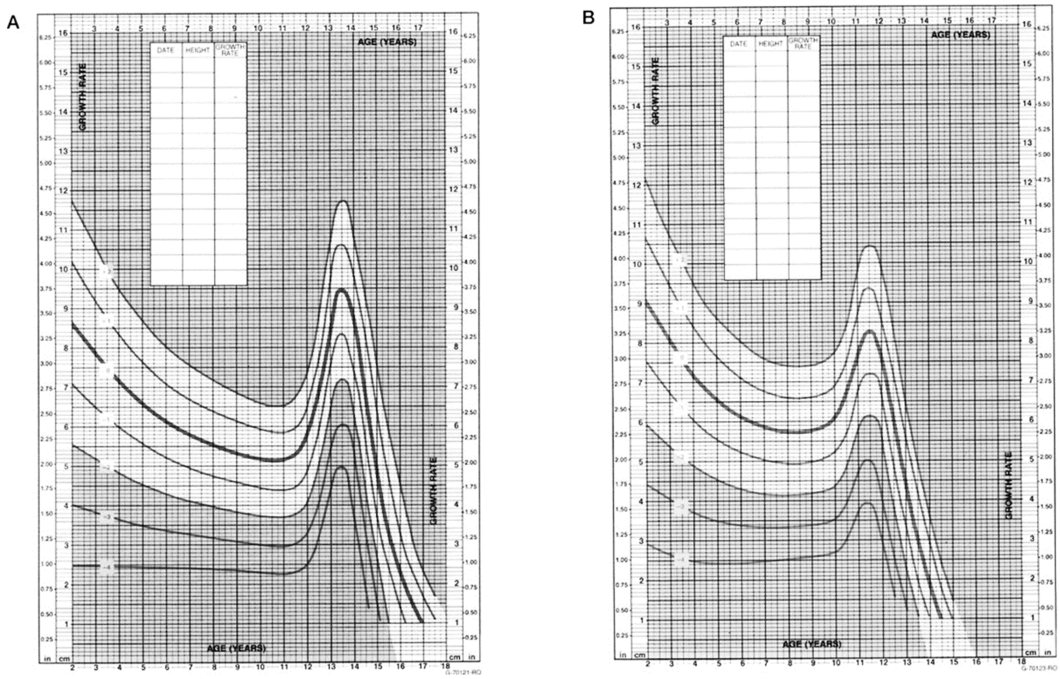


Figure 2.4: *Growth velocity charts of boys 2 to 18 years of age (a) and girls 2 to 15 years of age (b). Note the earlier entrance of females into the adolescent growth spurt and males greater velocity during this growth spurt. Source: Abbassi V. 1998. Growth and Normal Puberty*. Pediatrics *102: 509-510.*

A sharp decrease in velocity of growth is seen after PHV, around the ages of 16-17 years in females and 18-19 years in males (Hauspie and Roelants, 2012:60). In an environment that promotes normal growth, final adult stature should be reached around 16 years in females and 18 years in males (Binns, 1998:326). Growth can continue in an individual into their late-twenties depending on environmental conditions, however due to the decrease in velocity after the initial adolescent growth spurt, increase in stature is minimal (Karlberg, 1998; Hauspie and Roelants, 2012:60).

Changes to the body occurring throughout adolescence result in significant sexual dimorphism (Humphrey, 1998:58). Not only does final stature show significant differences between females and males, but also long bone lengths (Humphrey, 1998:66) and body fat (Cameron and Demerath, 2002). The increased amount of time spent within the childhood period for males contributes to this sexual difference

(Hauspie and Roelants, 2012:74). The two year delay in the ‘take-off’ stage for males and the greater velocity in growth at the onset of the adolescent growth spurt in females allows females to overtake males in development and stature (Gasser, 1985; Hauspie and Roelants, 2012). Despite females’ greater stature during the early stages of adolescence, they soon experience a significant deceleration after PHV, which is not as dramatic in males (Gasser, 1985). For example, the range in height gained during adolescence for females and males in one study was found to be 17-33 cm and 21-36 cm, respectively with an average of 16% of their total height gained during this period (Tanner *et al.*, 1976:112). However, the average stature gained during PHV in this study was 8.1 cm for females and 8.8 cm for males, as males spent a greater amount of time in PHV (Tanner *et al.*, 1976:112).

Unlike the rapid growth of the long bones (especially lower limbs) seen in the mid-growth spurt during childhood, growth during adolescence is more pronounced in the axial skeleton (Eveleth and Tanner, 1990; Karlberg, 1998; Bass *et al.*, 1999; Bradney *et al.*, 2000). Growth in the long bones ceases after fusion of the epiphyses, but small amounts of growth in the vertebral column can continue between 20 and 30 years of age (Tanner, 1989, 1990). The vertebral column and femur contribute the greatest percentage of total height in adult stature (Sciulli and Hetland, 2007). It is possible for an individual not to experience the adolescent growth spurt and to continue growing linearly and attain normal stature, though growth may continue until approximately 21 years of age in females and 24 years of age in males (Karlberg, 1998:111). If an individual is allowed to grow without any interruptions during development they will reach their genetic potential in regards to stature and body proportions specific to their population of origin (Ruff, 1991, 1994; Holliday and Ruff, 1997; Holliday, 1997a; Holliday and Hilton, 2010). Growth during adolescence is more controlled by genetics and is therefore more resistant to environmental effects (Stinson, 2000).

2.2.2 Sexual variation in growth

The commencement of the three growth periods varies between the sexes. Generally, females have greater acceleration and deceleration in growth during childhood (Tanner, 1989; Karlberg, 1998:111) and are shorter in stature than males up to adolescence (Tanner, 1989). However, because the adolescent growth spurt occurs earlier in females (Tanner, 1989), they tend to be taller than males between the ages of 11 and 13 years (Eveleth and Tanner, 1990). As a result of females entering the adolescent growth spurt earlier than males, the difference in lower limb length between males and females is quite large considering males experience a longer linear growth period during childhood (Tanner, 1989; Eveleth and Tanner, 1990). After the adolescent growth spurt, males have a greater stature than females (approximately 12-13 cm taller) caused by a combination of factors, including a longer period of childhood growth and a greater velocity of growth during the adolescence period (Tanner, 1989; Karlberg, 1998).

Differences between female and male growth may be a result of canalization; growth is better regulated in females with fewer environmental stressors impacting development (Brown and Townsend, 1982). Interestingly, males are more susceptible to environmental stresses (Greulich, 1951, 1957; Tanner, 1962) which can affect final adult stature attained, possibly increasing the amount of sexual dimorphism observed in a population (Hewitt *et al.*, 1955; Stini, 1972; Tobias, 1975; Wolanski and Kasprzak, 1976; Bielicki and Charzewski, 1977; Hall, 1978; Kuh *et al.*, 1991; Storey, 1998; Stinson, 2000; Schweich, 2005; Shin *et al.*, 2012). Since males seem to be more affected by changes in the environment it could lead to a longer growth period (Stini, 1972), allowing them to 'catch-up' if more favourable conditions return (Brown and Townsend, 1982). A much stronger stimulus must present itself for a change in stature in females to occur (Wolanski and Kasprzak, 1976; Storey, 1998).

2.3 Impact of Environment on Growth and Development

Environmental sources that could negatively impact the growth and development of non-adults include access to nutritional resources, health care, the likelihood of catching diseases or infections during childhood, and energy expended during activities in the past (Steckel, 1995). The general increase in stature seen within the last 150 years is most likely a result of improved nutrition, sanitation, access to medical care, higher degrees of education reached by both parents, and globalization (Eveleth, 2001:137) rather than evolutionary or migratory causes (Eveleth, 2001:139-140; Floud *et al.*, 2011:2; Rosenfeld, 2012:109). However, more recent research on people inhabiting the Netherlands point to a combination of natural selection and positive environmental influences for their continued increase in stature (Stulp *et al.*, 2015). The rapid change in technological advances means that climate no longer has such a profound impact on the growth and development of populations as it did in the past (Katzmarzyk and Leonard, 1998; Bogin, 2012b). With the improvement of environmental conditions, the growth period is now shorter, as evidenced by the cessation of growth at younger ages, especially in populations within the United States and Europe (Largo, 1999:157-158). For example, the age at menarche in females has decreased from 17 years to 13 years of age, demonstrating the earlier arrival of critical growth phases (Eveleth and Tanner, 1990). When analysing stature and body proportions in past populations the mixture of environment and genetics, various timings of possible nutritional deficiencies, disease and access to health care during childhood must be considered (Eveleth and Tanner, 1990; Komlos, 1995; Karlberg, 1998; Humphrey, 2000; Stinson, 2000; Wilson, 2001).

2.3.1 Adaptation to the post-natal environment

Three hypotheses have been proposed by various researchers to explain how developmental plasticity can be impacted by environmental stressors experienced during intrauterine development that can have health consequences in adulthood. These include Barker *et al.* (1989a,b) and Hales and Barker's (1992) Developmental Origins of Health and Disease (DOHaD), also known as developmental programming, Gluckman and Hanson's (2004) predictive adaptive response (PAR), and finally the intergenerational influence hypothesis (IIH) proposed by Emanuel (1986). All three hypotheses are described below.

2.3.1.1 Developmental Origins of Health and Disease (DOHaD)

The Developmental Origins of Health and Disease hypothesis, also known as developmental programming, is a theory developed by Barker and colleagues (1989a,b) to explain the link observed between low birthweight and increased risks of developing cardiovascular disease later in life (Cameron and Demerath, 2002; Kuzawa, 2012). Exposure to adverse environments during intrauterine development will result in lower birthweight and present long term impacts on adult health (Bogin *et al.*, 2007:633; Floud *et al.*, 2011; Norgan *et al.*, 2012:139). Maternal stress can therefore affect the growth and development of the unborn child (Barker, 1994; Floud *et al.*, 2011:12). These stressors experienced *in utero* and early childhood, disrupt the growth of various systems in the body and can lead to poor adult health (Bogin *et al.*, 2007: 633). Hales and Barker (1992) reported that preferential growth of certain vital tissues like the brain and heart will occur over the development of muscle and the endocrine pancreas. The preferential selection of maintaining the development of the brain was also noted by Rudolph (1984). These adjustments of the developing foetus could be a response to the intrauterine environment (Kuzawa, 2012).

The Dutch Hunger Winter study of those affected by famine induced by German occupation in western Netherlands in 1944-45 provides valuable information on the effect of malnutrition on development *in utero* (Schulz, 2010). Roseboom *et al.* (2006) found that individuals experiencing malnutrition during critical periods of gestational development displayed various adverse outcomes in adulthood. Those who were malnourished during the later periods of gestation had lower birthweights and continued to be small in body size; those experiencing famine early in gestational development were of normal birthweight, but were more likely to suffer from obesity and cardiovascular disease later in life. Individuals who experienced malnutrition during mid-gestation were at elevated risks of reduced renal function (Roseboom *et al.*, 2006). Post-famine food reserves quickly returned to normal, and thus, those who experienced this famine during gestation were maladapted to their post-natal environment leading to increased risks for chronic diseases (Bogin *et al.*, 2007:633). Rapid weight gain during infancy can lead to a higher risk of obesity, type II diabetes, and cardiovascular disease later in life (Cameron, 2003; Ong and Dunger, 2004; Ong and Loos, 2006; Lejarraga, 2012).

2.3.1.2 Predictive Adaptive Response (PAR)

The hypothesis posited by Gluckman and Hanson in 2004 focuses on the development of metabolic diseases caused by foetal environment (Norgan *et al.*, 2012). The predictive adaptive response states that the mother gives signals to the developing foetus based on the external environment and the foetus will adjust the rates of growth to best adapt to the post-natal environment predicted (Gluckman and Hanson, 2004; Norgan *et al.*, 2012:140). Gluckman and Hanson (2004) utilized the development of coat thickness of the meadow vole to explain this hypothesis. The intrauterine environment for the developing pup remains the same despite fluctuations in seasonality during gestation, however the predicted season (autumn or spring) in which the pup will be born into will dictate the thickness of their coat for when they leave the nest (Gluckman and Hanson, 2004:314). In humans, if the prediction of the post-natal environment is correct, then normal development will occur and a healthy individual will emerge; however if the predicted environment is not as expected the predictive adaptive response is incorrect (Gluckman and Hanson, 2004:314) and the individual will experience ill health during life (Wells, 2012:230). When the post-natal environment is better than predicted *in utero*, then an increase in growth is likely to occur resulting in overcompensation and possible complications with an increased risk of metabolic disease later in life (Bogin *et al.*, 2007; Norgan *et al.*, 2012:140). The predicted environment may not benefit the present, but may aid in the health of an individual in the future (Gluckman and Hanson, 2004:314). Therefore, migration to a nutritionally rich environment may increase the prevalence of diabetes if individuals originally inhabited an area poor in nutrition (Gluckman and Hanson, 2004:315).

Those critical of this hypothesis state that it is similar to weather forecasting as the foetus must predict the post-natal environment to which it will be born into from signals received *in utero* (Wells, 2012:230). Wells (2012) believes that the development of the foetus is a dynamic relationship between the mother and her offspring and it is this connection that influences developmental plasticity (pg. 232). An example that appears to contradict the PAR hypothesis is Martorell's (1995) analysis of Guatemalan children in the 1960s, 70s, and 80s (Norgan *et al.*, 2012). Children born in Guatemalan villages who most likely experienced adverse environmental conditions during foetal development were given energy and nutritional supplements to aid in early childhood development (Norgan *et al.*, 2012). Based on the PAR hypothesis these children should have been adversely affected and at an increased risk for developing metabolic conditions since their post-natal environment improved from their intrauterine environment, but this was not the case (Norgan *et al.*, 2012:141). They experienced improved work capacity and increased stature without accelerated maturation (Martorell, 1995). Wells (2012) stated that the dynamic relationship between mother and foetus allows for the gradual adaptation to new environments across generations (pg. 232).

2.3.1.3 Intergenerational Influence Hypothesis (IIH)

The Intergenerational Influence hypothesis was proposed by Emanuel in 1986, stating that health experiences in one generation can have an effect on the next generation in relation to growth and development (Emanuel, 1986:27). Therefore, previous generations experience *in utero* may be passed down to the child during their foetal development and is referred to as gestational imprinting or epigenetics (Norgan *et al.*, 2012:142). This hypothesis removes the ability of the foetus to change its growth based on signals provided by the mother *in utero* as it is largely the experiences of previous generations that impact growth and development (Norgan *et al.*, 2012:142). A study utilizing multiple generations of rhesus monkeys (*Macaca mullatta*) found that females with a higher birthweight gave birth to infants (both male and female) with higher birthweights, whereas mothers with lower birthweights gave birth to average males and underweight females (Price and Coe, 2000:452). It was also discovered that it took four generations to recover from a generation's undernutrition during pregnancy (Price and Coe, 2000).

This phenomenon can also be detected in humans. Varela-Silva and colleagues (2009) studied a Maya population within the Yucatan, Mexico and assessed various factors that could impact the growth of offspring. Their aim was to discover why children displayed increasing rates of obesity whilst still being stunted for their age. Mothers in the population who had suffered from malnutrition during foetal development and early childhood were more likely to have offspring who would experience health problems later in life. At the time when these individuals were assessed, their environment was in a transition from the more traditional lifestyles of the Maya culture to one involving access to a greater variety of imported resources (Varela-Silva *et al.*, 2009:657). Though the mothers may have experienced malnutrition during foetal development, their offspring will be raised in an environment with greater access to food resources, albeit some of these resources may provide energy and not necessarily nutrition (e.g. high sugar/fat). The predisposition of this population to store energy has resulted in a propensity to obesity (Varela-Silva *et al.*, 2009:657). Similarly, parents of short stature caused by undernourishment during their early childhood development are more likely to have children exhibiting reduced growth as a result of their early childhood experiences, whereas children born to parents who had a healthier childhood will have a better chance of reaching their full genetic potential in regards to stature and body proportion (Bogin and Loucky, 1997). Within this theory, it is best to visualize growth and development as nesting dolls as the experiences of previous generations are embedded in future generations (Gowland, 2015).

2.3.2 Nutrition and growth

As discussed in the previous section, proper nutrition is key to the growth and development of humans (Bogin, 2012b). Nutrition is the input of solid and liquid forms of food into the body to help maintain and promote growth, organ function, and energy of an individual (Norgan *et al.*, 2012:124). Periods of malnutrition, poor hygiene, and adverse environmental conditions can lead to the deceleration of growth during critical periods of development (Largo, 1999:157; Cardoso, 2005; Schillaci *et al.*, 2011:318). Food is fuel for children and restriction of nutritional resources will arrest growth until proper levels of adequate nutrition can be resumed (Steckel, 2008). A decrease in weight occurs prior to the cessation of linear growth or height (Lejarraga, 2012:34). Stunting is the shortened height for chronological age of an individual displaying normal weight for height, indicating chronic malnutrition (Lejarraga, 2012). Wasting indicates acute malnutrition and can be associated with the increased risk of disease or death (Lejarraga, 2012). Chronic malnutrition makes it difficult for an individual to completely ‘catch-up’ in their original height trajectories, even if a return to normal nutritional intake occurs (Lejarraga, 2012:35).

Examples of malnutrition can be found throughout the world. However, slowed growth is most frequently documented in developing countries in individuals that are 6-12 months of age; a time where breast milk no longer provides adequate nutrition to support a growing individual and the supplementation of solid food is necessary for the energy required to grow during critical periods (Norgan *et al.*, 2012:139) The inability to reach one’s full genetic potential in height is multifactorial and not only includes nutritional imbalance, but the presence of infections and social circumstances (Norgan *et al.*, 2012). Despite receiving adequate nutrition, there are some infections, such as diarrhoeal disease, which prevents individuals from absorbing sufficient nutrients from their food (Tanner, 1989). Any type of malnutrition delays growth in children, however, children have the ability to recover from these delays with access to better resources (Tanner, 1989). This is dependent on the duration of undernutrition; if the delay does not last for long periods, it is possible that catch-up growth may occur (Eveleth and Tanner, 1990; Wilson, 2001; Steckel, 2008). Once this stressful period is alleviated it is possible to return to normal or even accelerated growth (up to three times its normal velocity) to reach growth trajectory (Tanner, 1981; Stinson, 2000). If catch up growth were to take place in an individual's life, it could disguise periods of negative environmental effects, such as malnutrition (Steckel, 2008). Malnourishment or disease early in life may make it more difficult for an individual to catch-up (Eveleth and Tanner, 1990; Harrison, 1990; Vercellotti and Piperata, 2012).

2.3.3 Catch-up growth

Catch-up growth can be viewed as an adaptation when resources needed for normal growth and development are unavailable and growth is delayed until they are available (Tanner, 1989, 1990; Eveleth and Tanner, 1990; Vercellotti and Piperata, 2012) and an individual then returns to his/her original growth canal (Hauspie and Roelants, 2012:65). The ability to catch-up in development is dependent upon when the delay in growth occurs and whether the individual will have enough resources to support accelerated growth in order to return to normal development (Steckel, 1995). The tempo of growth is under greater genetic control, however the body can adapt during times of stress by delaying or slowing growth (Hauspie and Roelants, 2012:65). There are three types of catch up growth according to Tanner (1981). Type 1 is seen most frequently in infancy and childhood, whereas Types 2 and 3 are seen during adolescence (Largo, 1999:161-162). Type 1 catch-up growth occurs when an individual is no longer under the constraints of the intrauterine environment and a rapid increase in growth can occur during infancy (Cameron and Demerath, 2002:166). Type 2 catch-up growth occurs when the cause of stress is removed. This causes a delay in growth and extends the period of time spent in the growth period with the individual experiencing normal growth velocity. Finally, Type 3 is a combination of Type 1 (increased velocity after insult) and Type 2 (prolonged period of growth) (Largo 1999:161-162). More than 50% of infants experience catch-up or catch-down growth during the first two years of life (Cameron, 2012). For example, an infant may have genetically tall parents, but constraint during intrauterine development inhibited growth and therefore the infant experienced rapid growth after birth. The opposite can be said for individuals with genetically short parents who experienced a positive intrauterine environment and thus a catch-down in growth post-birth (Lejarraga, 2012).

Catch-up growth can not only accelerate growth in an individual, but it can also prolong the period of time spent in one of the three growth periods (Steckel, 1995). There are two pathways to catch-up growth: true catch-up growth and complete catch-up growth (Tanner, 1989). True catch-up growth occurs when growth velocity is increased until the normal growth curve of an individual is reached (Tanner, 1989:166). Complete catch-up growth occurs when there is no increase in growth velocity, so to compensate, the growth period is extended until the full genetic potential of stature is reached (Tanner, 1989:166-167). An example of remarkable catch-up growth in a past population was the growth of slave children in the United States (Steckel, 1995, 2008). Though American slave children displayed stunted growth during childhood, the adult population demonstrated stature comparable to European nobility. Surprisingly, those that survived past childhood were just slightly shorter than Union Army soldiers, and just two inches shorter than the average modern day males and females (Steckel, 2008:141). Not all slaves experienced this remarkable catch-up growth during childhood, as slaves from the Caribbean displayed shortened stature to slaves from the United States (Steckel, 1995). Steckel (1995) hypothesizes that a greater variety of crops and wider spaces in which to cultivate them in the United States may have played a role in the American slaves' catch-up growth (pg.1925). A bioarchaeological example of catch-up growth is found in the Ancestral Pueblo Indian population where a period of catch-up growth occurred after five years of age (Schillaci *et al.*, 2011:322). The ability to catch-up in growth is entirely dependent on when these disruptions occur, how long the disruption lasts, and finally its severity (Cameron, 2012:13; Lejarraga, 2012:6).

2.4 Chapter Summary

This chapter provided historical background regarding the study of human growth and development, from its earlier days in Greece, through to modern studies of living populations. It also discussed the different developmental stages of growth in humans, with brief explanations of how these developmental stages are presented within the skeleton and how certain aspects of growth promote sexual dimorphism in areas of the body. Three theories on the impact of the intrauterine environment on the developmental plasticity of the human body in the post-natal environment were presented. Stress experienced during intrauterine development has the potential to influence development in the post-natal environment, but external forces such as nutrition also play a role in growth and development. During periods of stress the body has the capability to slow growth until a return to 'normalcy' is reached, by which the body may try to catch-up in growth. All information presented within this chapter will impact the interpretation of stature and body proportions during the period in question, as insights on growth and development of humans is required (Ulijaszek, 1998).

Chapter Three: Stature and Body Proportions

3.1 Introduction

In *On the Origin of Species,* Darwin refers to the ability of humans and other mammalian species to adapt to their local environment, through a combination of acclimatisation and natural selection (Darwin, 1909 [1859]). The term acclimatisation refers to slow changes that occur throughout life that reduce stress, whilst natural selection is the mechanism by which traits are selected for, or against, for future generations (Frisancho, 1993:5). In 1969, Lasker added another biological adaptation, which is referred to as plasticity, or the ability of the human body to respond with phenotypic alteration (Serrat *et al*., 2008) caused by changes in the environment during growth and development (Bogin and Loucky, 1997:17): "In Darwinian terms, the ecosystem is the setting for the struggle for existence, efficiency and survival are the measure of fitness, and natural selection is the process underlying all products" (Frisancho, 1993:9). This process has led to the variation seen globally in human populations (Eveleth and Tanner, 1990; Bogin, 1999). Stature and body proportions are diverse due to a variety of biocultural factors such as nutrition, socioeconomic status, hygiene, and healthcare (Bogin *et al*., 2002; Schweich, 2005) and/or biogeographic patterns (Temple, 2011). This variation in human stature can be illustrated by the substantial differences in height throughout the globe. For example, those with the shortest stature in the Netherlands (reported to be the tallest population in the world) are taller than the average stature of those inhabiting Central and South America (Bogin, 1999). Worldwide variations in stature for modern day female and male populations range from 136 cm to 144 cm, respectively, in Efe Pygmies of Africa to 171 cm to 184 cm in females and males, respectively, in the Netherlands (Bogin, 2012b:352). The diversity of the human body with regard to stature and body proportions is caused by both genetic and environmental factors (Tanner, 1990; Bogin, 1999; Gustafsson *et al.*, 2007; Giannecchini and Moggi-Cecchi, 2008). Two-way interaction between humans and their environment alter the physical appearance (phenotype) of humans (Ruff, 1994; Giannecchini and Moggi-Cecchi, 2008; Cardoso and Gomes, 2009), whilst shaping the environment to best fit their needs through biocultural means (Wolanski and Kasprzak, 1976:548). Modern humans are a product of their ancestors' acclimatisation to the local environment as well as their adaptation to their surroundings (Bogin, 1999).

In bioarchaeology, one way to assess human adaptation to local environments is through the study of anthropometry and osteometry in human skeletal remains (discussed in Chapter Two). In previous years, many anthropometric studies were focused on the measurement of the cranium (craniometrics) with the aim of producing racial categories (Gowland and Thompson, 2013). These measurements were used to reinforce the idea that white males were somehow superior to women and all other races (Gould, 1997; Epstein, 2004). An early critic of using craniometrics to classify humans into racial categories was Franz Boas (Gowland and Thompson, 2013). He demonstrated that these measurements changed throughout growth and development, as well as inter-generationally (Caspari, 2009; Gowland and Thompson, 2013). These morphological characteristics are a result of an individual's genetics, culture, and adaptation to their local environment (Lasker, 1994:4; Gowland and Thompson, 2013:121). Lasker (1994) states:

> Thus despite reservations about past uses and abuses of anthropometrics, it can be seen that they are suitable and adaptable to many scientific and applied problems about human biology including changes over time in respect to growth or evolution…applications to forensic identification, objective signs of physical fitness or illness, and the relative genetic and environmental components of various aspects of human physique under various circumstances including nutritional and other stresses (pg. 6).

Currently, anthropometric and osteometric measurements are undertaken with the aim of assessing general health, nutrition, social inequality, sexual dimorphism, inter- and intra-population variation in body size and shape, and microevolution (Frayer, 1980; Kunitz, 1987; Steegmann and Hasely, 1988; Formicola and Franceschi, 1996; Bogin and Keep, 1999; Formicola and Giannecchini, 1999; Steckel and Rose, 2002; Kron, 2005; Raxter *et al.*, 2008, Vercellotti *et al.*, 2009; Béguelin, 2011; Ruff *et al.*, 2012). Many researchers analyse the stature and body proportions of populations inhabiting a single geographic region through time (Cardoso and Gomes, 2009; Ulijaszek, 1998), with a majority of those focusing on changes in stature (Frisancho, 1990, 2008; Bogin, 1999; Steckel, 2004; Larsen, 2015), rather than body proportions (Vercellotti *et al.*, 2012:204). It is important to address body proportions in combination with changes in stature as both impact one another. Differences in stature can arise through variation in limb proportions, whilst stature may also remain stable despite an alteration in limb proportions (Sjvøld, 1990; Béguelin, 2011). This chapter discusses the development of stature studies from skeletal remains, summarises the findings of previous studies regarding stature variation and discusses the significance of body proportions in terms of ecogeographic patterns and diachronic changes.

3.2 Stature

3.2.1 Background

The study of stature in the past has been utilized by historians, economic historians, bioarchaeologists and anthropologists (Kunitz, 1987; Harrison, 1990; Steckel, 1995; Bogin, 1998; Waldron, 1998; Jantz and Jantz, 1999; de Mendonça, 2000; Bogin *et al.*, 2002; Duyar and Pelin, 2003) to assess the quality of life (Tanner, 1986; Komlos, 1994; Steckel, 1995; Bogin and Keep, 1999; Sládek *et al.*, 2015; Mays, 2016). Historians have used stature to assess biological living standards and social class distinctions in different populations through time. Within bioarchaeology, the calculation of stature has frequently been used to assess the general health status of past populations and continues to be utilized despite inherent issues in current methodologies available (see sections 3.2.3, 3.2.4, and 3.2.5 for details).

Estimates of stature from skeletal remains have been undertaken for many years (Meiklejohn and Babb, 2011). One of the earliest was performed by Manouvrier in AD 1892 and AD 1893 (Meiklejohn and Babb, 2011). Manouvrier utilized long bone lengths and stature from a data-set collected by Rollet of 100 French cadavers with the aim of predicting stature based on individuals who presented the same lengths of long bones (Trotter and Gleser, 1952:463-464). In AD 1888, Rollet also used his data-set to predict the long bone lengths of individuals with the same stature (Trotter and Gleser, 1952:463-464). In AD 1899, Pearson, using Rollet's data, created regression formulae to calculate stature from long bones (Meiklejohn and Babb, 2011). In the 1950s, the often cited Trotter and Gleser (1952/1958) and Dupertuis and Hadden (1951) used the Terry Collection and Todd Collection, respectively, to produce formulae for estimating stature from long bones. Due to differences in body proportions seen in the ‘white’ and ‘black’ females and males within these collections, separate formulae were created for each ‘racial’group. Different formulae were created for these ‘racial’ groups because they exhibited different body proportions. Recently, researchers have argued for the need for population specific regression formulae to calculate stature, with new formulae created for Native American (Sciulli *et al.*,1990; Sciulli and Giesen, 1993), central Europeans (Hauser *et al.*, 2005; Vercellotti *et al.*, 2009), and Ancient Egyptians (Raxter *et al.*, 2008), due to ecogeographic variation in body proportions.

3.2.2 Methods of estimating stature

Two types of methods are currently available to bioarchaeologists attempting to reconstruct living stature from human skeletal remains; the anatomical method and the mathematical method (Raxter *et al.*, 2006). The anatomical method directly reconstructs living stature through the measurement of all skeletal elements that directly contribute to height, whilst the mathematical method uses regression formulae created from correlations of upper and lower long bone lengths to living stature (Raxter *et al.*, 2006). Of the two methods, the anatomical reconstruction is more accurate as it allows researchers to account for differences in body proportions such as changes in lower limb length compared to trunk or vertebral height (Raxter *et al.*, 2006, Maijanen, 2009; Maijanen and Niskanen, 2010; Shin *et al.*, 2012; Sládek *et al.*, 2015). The benefit of using the mathematical method is that, at the minimum, only one long bone measurement is needed to estimate stature. It is important to recognize that each of these methods has associated errors and a critique of each is presented below.

3.2.2.1 Anatomical method

The anatomical method requires that all skeletal elements directly associated with stature are measured. These estimates can then be used to create population specific regression formulae (the mathematical method). This approach has been employed successfully in numerous studies (Sciulli *et al.*, 1990; Sciulli and Giesen, 1993; Formicola and Franceschi, 1996; Sciulli and Hetland, 2007; Raxter *et al.*, 2008; Vercellotti *et al.*, 2009; Sládek *et al.*, 2015; Mays, 2016). In total, 28 measurements from 29 skeletal elements are necessary to estimate stature using the anatomical method (see Chapter Four). Often in archaeological contexts, not all skeletal elements are preserved or complete to measure. To encourage researchers to employ this method of stature estimation, Auerbach (2011) created formulae to estimate missing or taphonomically damaged skeletal elements necessary for stature calculation. Numerous formulae have been created to estimate vertebral body heights (only when lumbar vertebrae are present) and talocalcaneal height (only when femora and tibiae are present) (Auerbach, 2011). Though there are errors associated with the estimation of missing skeletal elements, Auerbach (2011) states that the error associated with these estimations is within the measurement error and therefore minimal (pg. 78). These calculations enable bioarchaeologists to obtain a larger sample size for estimating stature using the anatomical method.

A comprehensive study of stature utilising the anatomical method was undertaken in 1956 and henceforth is referred to as the Fully anatomical method (Raxter *et al.*, 2006). Fully identified and examined French soldiers killed during World War II at a German concentration camp in Austria (Raxter *et al.*, 2006). The stature recorded by Fully was then compared to military records or family members' descriptions of these to determine the effectiveness of estimating stature using this method (Raxter *et al.*, 2006). Forty years later, Raxter and colleagues (2006) tested the accuracy of Fully (1956) and Fully and Pineau (1960) anatomical methods by measuring 119 black and white individuals from the Terry Collection and comparing results to the cadaveric stature reported in Trotter and Gleser's (1952) study of the same collection. Fully's (1956) technique underestimated living statures by as much as 2.4 cm in some individuals, therefore revisions to the soft tissue correction calculations were created and later published (Raxter *et al.*, 2006, 2007). Corrections are applied to incorporate soft tissues (such as the intervertebral discs) to the skeletal height in order to calculate living stature. Due to changes in stature throughout the ageing process, new soft tissue correction formulae were created for individuals with known ages/age ranges (age-corrected formula), and unknown age of skeletal remains (non-age-adjusted formula) (Raxter *et al.*, 2006, 2007). No differences between sex or ancestry were detected in living stature estimations when using these soft tissue corrections (Raxter *et al.*, 2006).

In their study, Raxter and colleagues' (2006) revised Fully anatomical method of estimating living stature was accurate within ±4.5 cm from the known cadaveric statures in 95% of the 119 individuals analysed. The mean difference between known and estimated stature was 0.01 cm when controlling for age (Sciulli and Hetland, 2007:106). Several studies (Raxter *et al.*, 2008; Vercellotti *et al.*, 2009; Auerbach and Ruff, 2010; Sládek *et al.*, 2015) utilize the soft tissue correction from Raxter *et al.* (2006, 2007) to calculate living stature instead of just skeletal height. According to Auerbach and Ruff (2010), living stature estimates are "considered more useful in comparative studies; comparability in skeletal statures among human groups has not been established" (pg. 197). In Maijanen's (2009) assessment of multiple anatomical methods, it was discovered that measurements of vertebral bodies have the potential to affect skeletal height outcomes. These methods were compared to documented cadaver stature estimates of the WM Bass Donated Skeletal Collection. Variations in measurements of the vertebrae (midline body, maximum body, anterior body, and posterior body) played a larger role in stature differences than other skeletal elements constituting stature. Though there are slight differences in methods and errors associated with estimating stature from skeletal remains, Maijanen (2009) recommended using the anatomical method whenever possible as it was more accurate and reliable than employing long bone regression formulae (pg. 751). This belief is repeated by Mays (2016) as the anatomical method is more strongly correlated to stature than long bone lengths and therefore tends to report more accurate stature estimates than through the use of long bone lengths alone (pg. 647).

Despite the greater accuracy in calculating stature utilizing the revised Fully anatomical method, this technique remains underused in skeletal populations and has yet to be systematically applied to Romano-British and Early Medieval populations. The only application of this method in Great Britain was on a Medieval sample from Wharram Percy (Mays, 2016). The variability in preservation and completeness of human skeletal remains discovered in archaeological contexts coupled with the time-consuming nature of the anatomical method, deters bioarchaeologists from using this method and instead the mathematical method is most commonly used to estimate stature (Vercellotti *et al.*, 2009).

3.2.2.2 Mathematical method

The mathematical method uses regression formulae derived from measurements of a specific known height reference population. The most widely applied regression formulae are from Trotter and Gleser (1952, 1958) and Trotter (1970) (Kunitz, 1987). It is best to use population specific formulae when estimating living stature from human skeletal remains because there are global variations in body proportions, which if unaccounted for, will generate incorrect stature estimates (Holliday and Ruff, 1997; Formicola and Giannecchini, 1999; Raxter *et al.*, 2008; Vercellotti *et al.*, 2009; Ruff *et al.*, 2012). Some of these population specific formulae include Allbrook (1961) (British and East African Males), Genovés (1967) (modern Mesoamerican and US Southwest), and Giannecchini and Moggi-Cecchi (2008) (Central Italy), de Beer (2004) (Dutch), Vercellotti *et al.* (2009) (Medieval Poland), Maijanen and Niskanen (2010) (Medieval Sweden), Formicola and Franceschi (1996) (Neolithic Europe), and Sládek *et al.* (2015) (Medieval Czech Republic).

Bioarchaeologists must exercise caution when applying mathematical regression formulae to past populations. Ecogeographic variation and environmental stressors experienced throughout growth and development can change body proportions, especially torso height and lower limbs. Correlations between long bone lengths and stature will vary and can lead to incorrect estimates (Vercellotti *et al.*, 2009). Therefore, it is best to use equations based on populations demonstrating similar body proportions to the population being analysed (Feldesman *et al.*, 1990; Konigsberg *et al.*, 1998; Holliday, 1999; Raxter *et al.*, 2006; Sciulli and Hetland, 2007; Auerbach and Ruff, 2010). When trying to determine which set of published regression formulae most accurately reflect the population being studied, Brothwell and Zakrzewski (2004) recommend calculating stature using all long bone elements of an individual from various formulae and determining which set of equations presents the smallest spread in stature estimations. Unlike the anatomical method, sex and ancestry of skeletal remains must be assessed prior to calculating stature due to variation and sexual dimorphism (Sciulli and Hetland, 2007). Despite its varying accuracy, bioarchaeologists continue to utilize this method due to the speed and ease with which the calculations can be made as well as issues of preservation.

The use of Trotter and Gleser (1952) and Trotter (1970) formulae for British archaeological remains has been recommended in several handbooks (e.g. Mays, 1998; Waldron, 1998; Brothwell & Zakrzewski, 2004; Roberts, 2009), as it was believed to represent a population (Terry Skeletal Collection and US casualties from WWII) that would present similar body proportions as past populations in Britain (Mays, 2016). Trotter and Gleser's 1952 publication was revised to include a larger sample of male individuals with measured stature from the Korean War (Trotter and Gleser, 1958). Thus the equations for calculating male stature within Trotter and Gleser's 1952 publication are different to those within their 1958 publication. Mays (2016) highlighted the lack of consistency in formulae chosen to estimate stature within various studies of archaeological human skeletal remains recovered from Britain (pg. 647).

3.2.2.3 Comparing the anatomical and mathematical methods

Researchers have compared the anatomical method described by Fully (1956) with Trotter and Gleser's (1952, 1958) mathematical regression formulae to determine which is most accurate in estimating skeletal height (Raxter *et al.*, 2006). Lundy (1988) assessed both the anatomical method and Trotter and Gleser's (1958) formulae utilizing three males of known stature. The anatomical method was determined to be just as accurate, if not more accurate, than Trotter and Gleser's (1958) formulae (Raxter *et al.*, 2006). As stated in section 3.2.2.1, Maijanen (2009) assessed stature calculated from the anatomical method on the well documented William M Bass Collection. These calculations were used to establish which skeletal measurements were most accurate in estimating skeletal height, finding that Fully most likely did not use the same vertebral measurement as Raxter and colleagues (2006), as it underestimated living stature (Maijanen, 2009). Underestimation using this vertebral measurement was also noted by Raxter *et al.* (2006), however their soft tissue corrections account for this discrepancy. This underestimation of stature using Fully's (1956) method is especially evident when analysing black populations (King, 2004; Bidmos, 2005) and may be due to correction factors of soft tissue that were originally developed from European populations, a lack of clarity on how Fully executed his measurements, or errors in cadaveric measurements.

It must be remembered that the estimation of stature from skeletal elements does present errors. Brothwell and Zakrzewski (2004) and Goldewijk and Jacobs (2013) both advocate the comparison of raw long bone lengths to assess health rather than the calculation of stature due to these errors. This approach, however neglects the important role of the vertebral column. Mays (2016) recommends that the anatomical method be employed if possible when analysing a skeletal collection and then compare calculated stature using various mathematical regression formulae to determine which publication produces the best estimates (pg. 8). If the estimation of stature cannot be done using the anatomical method, it is suggested that raw long bone lengths be compared instead.

3.2.2.4 Revising the stature of previously estimated populations

Bioarchaeologists continue to utilize Raxter *et al.*'s (2006) revision of Fully's anatomical technique to determine the accuracy of commonly used regression formulae (Raxter *et al.*, 2008; Auerbach and Ruff, 2010; Béguelin, 2011; Sládek *et al.*, 2015; Mays, 2016). Vercellotti and colleagues (2009) examined the accuracy of commonly used regression formulae for European populations by reconstructing stature from the anatomical method and creating new populations specific formulae. When the new formulae created from the anatomical method were compared to the most commonly used regression formulae for that population, the accuracy of the newly created formulae was found to be greater (Vercellotti *et al.*, 2009). The most accurate human skeletal elements for estimating living stature are those of the lower limb (femur and tibia) and the least accurate are those of the upper limb (humerus and radius) (Vercellotti *et al.*, 2009). Other studies demonstrating this lack in correlation between the upper limbs and stature include Trotter and Gleser (1952, 1958), Genovés (1967), Lundy and Feldesman (1987).

In the quest to estimate stature of a Native American population in Ohio using the anatomical method, Sciulli and Hetland (2007) discovered that formulae from Trotter and Gleser (1958) and Genovés (1967) inadequately estimated stature in this prehistoric Native American population of the Ohio Valley in North America. New population specific regression formulae were created specifically for Native Americans (Sciulli and Hetland, 2007). Continuing to analyse this difference in stature calculations throughout North America, a later study by Auerbach and Ruff (2010) discovered that limb proportions of various populations throughout North America were different. Due to these differences, several regression formulae needed to be created to accurately predict stature in various populations throughout North America (Auerbach and Ruff, 2010). Those populations with shorter average statures tend to inhabit the Arctic, Pacific Northwest and Western Plateau; these shorter average statures were due to shortened tibiae relative to overall stature (Auerbach and Ruff, 2010). With regard to European stature, Ruff and researchers (2012) utilized the anatomical method in 501 human skeletal remains dating from the Mesolithic to the 20th century to develop regression formulae to be utilized for human skeletal remains from Europe dating throughout the Holocene. They recommend using these formulae instead of Trotter and Gleser's (1952, 1958) as they were created using a modern sample. Generally, their formulae are more likely to account for differences in body proportions than those based on modern populations and they suggest researchers utilize these equations if more population specific regression formulae are not available (Ruff *et al.*, 2012).

Though these population specific formulae tend to be more accurate in estimating stature, Konigsberg *et al.* (1998) discovered that it was harder to estimate stature with individuals on the extreme ends of the spectrum of a population. Even within the same population, some researchers suggest the need for regression formulae to be created for three subgroups in a population: those of normal height, those who are taller than the population average, and those who are shorter than the population average (Duyar and Pelin, 2003). Duyar and Pelin (2003) recommended using tibial length to determine which subgroup each individual in the population was associated with, to assess which regression formula to utilize to calculate their stature.

3.2.2.5 Critiques of stature estimation

There are challenges to the estimation of stature from human skeletal remains. Within the field of forensic anthropology, these difficulties include the mismeasurement of the living, differences between individuals' reported stature versus their actual stature, changes in stature to long bone length ratios, and the mismeasurement of bones (Ousley, 1995). Though bioarchaeologists do not have issues with mismeasurement of the living or reported stature from individuals, they must consider fluctuations in body proportions from different geographic locations, temporal trends, the mismeasurement of skeletal elements, and errors associated with the methods presented above.

Body proportions are the result of genetic and environmental conditions experienced during growth and development. These proportions often follow an ecogeographic pattern whereby those inhabiting warmer climates demonstrate different body proportions than those living in colder climates (see section 3.3.1 for more details). The ratio of various skeletal elements to total stature can fluctuate based on these patterns and the health of an individual during growth, often making it difficult for bioarchaeologists to choose the appropriate mathematical regression formulae to calculate stature. Recommendations have been made by different researchers to accommodate these inherent issues with the estimation of stature (see section 3.2.2.3) including the use of the anatomical method to test various regression formulae to establish which is most appropriate.

Another point that must be acknowledged is the mismeasurement of skeletal elements, especially the tibia. Arguments have arisen between researchers in the way in which tibial length is measured in Trotter and Gleser' (1952) often cited publication; did Trotter include or exclude the medial malleolus in her measurements of the tibia? Jantz and colleagues (1994, 1995) discovered through repeated analyses that Trotter *did not* include the medial malleolus in the 1952 publication, which changes the way these equations are employed. This measurement was recently tested on a skeletal population from medieval England for which numerous complete skeletons were available and stature calculated using the revised Fully anatomical method (Mays, 2016). As part of this study, both measurements (with and without the inclusion of the medial malleolous) were taken to determine the impact these measurements had on the calculation of stature. Mays (2016) concluded that not including the medial malleolus presented lower stature estimations in the Wharram Percy sample (pg. 8). Therefore, caution must be taken when utilizing the measurement Trotter and Gleser's (1952, 1958) formulae for the tibia. Many studies explicitly state how measurements of skeletal elements were taken and now use the measurement of the tibia including the medial malleolus and excluding the intercondylar spines (Buikstra and Ubelaker, 1994).

3.2.3 Stature as an indication of overall health

Approximately 90% of variation in height is believed to be genetic in origin, whereas the remaining 10% is caused by environmental influences (Henneberg, 2001:159). Despite a large percentage of stature being under genetic control, "any secular changes in the height of humans over the evolutionary history of *Homo sapiens* probably reflect nutritional and environmental factors, rather than major genomic changes" (Rosenfeld, 2012:109). It is unknown whether populations with different genetic backgrounds that inhabit locations with similar environmental conditions will exhibit the same stature. Though stature is under heavy genetic control, it has the ability to inform researchers of possible insults experienced during the process of growth. For example, population movement to a different environment will invariably impact the health of migrants. The introduction of foreign pathogens from their new environment, along with the stress of emigrating not only has the ability to impact stature, but overall health (Steckel, 2012:234).

One reason researchers must consider the entire growth process and body proportions when examining adult stature is that it is a consequence of net nutrition throughout the growth period (Steckel, 2012:226). The assessment of growth through the use of anthropometric measurements has the potential to detect possible nutritional deficiencies experienced throughout the growth process and could indicate delayed growth (Norgan *et al.*, 2012:137). For example, Satyanarayana and colleagues' (1989) longitudinal study of rural Indian boys found that those classified as undernourished entered puberty later in life than Indian boys considered well-nourished and contemporaneous British cohorts. This delayed entry into puberty also increased the amount of time spent in the adolescent growth spurt. Interestingly, the rural boys presented similar gains in stature during adolescence as the well-nourished boys, however, they remained shorter in overall stature (Satyanarayana *et al.*, 1989:295-296).

The use of stature alone to assess quality of life and health provides an incomplete picture as the body has the ability to catch-up in growth if a return to an adequate environment occurs, disguising the previously experienced periods of stress (Steckel, 2012:227). This makes it difficult to assess whether an individual reached their genetic potential in stature, therefore, it is necessary to use contextual evidence from human skeletal material when attempting to reconstruct possible stress experienced during growth and development from stature (Goodman and Martin, 2002). This includes looking at non-specific stress indicators (i.e. dental enamel hypoplasia, cribra orbitalia, periosteal new bone formation) and specific indicators (vitamin D or C deficiencies, infectious diseases) in human skeletal remains.

3.2.4 Socioeconomic status

Many researchers utilize differences in stature over time (Gustafsson *et al.*, 2007; Cardoso and Gomes, 2009) to assess the effect of socioeconomic status, nutrition, and cultural practices on growth and development (Steckel, 2012:225). Correlations have been found between poor nutrition and lower socioeconomic status and shorter stature (Bharati, 1989: 529). Differences in stature across countries are not only due to variation in environmental conditions, but also correlate with income inequality

(Steckel, 2012:231). Inequalities between higher and lower socioeconomic groups demonstrate extreme differences in overall stature attained in adulthood. This relationship was demonstrated as early as AD 1829 by Villermé (Bharati, 1989). In addition to modern studies, stature recorded from the Marine Society of boys from impoverished areas of England during the mid-18th century AD demonstrated that poorer boys were significantly shorter than those of similar age dating to the 1960s (Floud *et al.*, 1990). This difference in stature was not only detected in the lower socioeconomic classes of the 18th century AD, but also within the upper classes, with children reaching the 25th percentile in stature when plotted on modern day growth charts (Floud *et al.*, 1990).

Some researchers state that due to the strong genetic control of stature, improvements in socioeconomic status alone cannot account for the increases observed in more recent populations (Henneberg, 2001:165). This argument, however, is countered by studies correlating increased socioeconomic status with increasing stature (Wolanski, 1979, 1995; Gurri and Dickinson, 1990). For example, the increase in leg length of individuals from Poland (Wolanski, 1979, 1995) and Mexico (Gurri and Dickinson, 1990) was due to an improvement in environmental conditions and not through genes alone (Bogin *et al.*, 2001:208). It is a complex combination of endocrine and neurological systems along with environmental influences on growth (Bogin *et al.*, 2001:216-217) that affect adult stature attained (Stulp *et al.*, 2015).

3.2.5 Sexual dimorphism in stature

In general, males tend to be taller than females; however the degree of sexual dimorphism within a given population differs from one place to another depending on environmental and cultural conditions (Bharati, 1989:529). In modern populations, a 7% difference in adult stature between females and males is the norm (Rosenfeld, 2012:111). Stature differences between the sexes are due to the increased time spent in the childhood growth phase by males and earlier fusion of epiphyses in females (Rosenfeld, 2012:111). This is highlighted with a 12.2 cm difference in stature of the Zürich Longitudinal Growth Study (1955-1976) between females and males (Gasser, 1985:137).

In a study comparing sexual dimorphism in stature between black, white, and Native Americans conducted by Eveleth (1975), Native Americans displayed the greatest amount of sexual dimorphism of the three groups, despite their smaller stature overall. It has been proposed that this difference might be due to genetic factors or the differential social treatment of males in this society (Eveleth, 1975:38). Studies by Hiernaux (1968) of African and Tobias (1970, 1972) of European populations discovered the greatest amount of sexual dimorphism is usually observed in well-nourished populations (Eveleth, 1975:35; Bharati, 1989:530). A smaller degree of sexual dimorphism in stature may not be caused by lower socioeconomic status alone, but by the stunting of males due to their reduced ability to buffer environmental stresses experienced during growth and development (Eveleth, 1975:35; Bharati, 1989: 530).

3.2.6 Studies of past populations

Many of the aforementioned studies of stature were conducted on living populations dating to the 20th century. The following sub-sections provide a brief overview of some of the key bioarchaeological studies of stature from a variety of periods and geographic locations.

3.2.6.1 North America

Plains Indians from 19th century North America were the tallest in the world during this time period with average statures of 172.2 cm (1-2 cm taller than contemporaneous European and American soldiers) (Steckel and Prince, 2001). This larger average stature could be attributed to differences in lifestyle and environmental experiences between the Plains Indians and other American and European populations. The tribes of the Plains Indians were highly mobile, existed in small populations, acquired fewer possessions, enjoyed a rich and varied diet, and illustrated a more egalitarian community (Steckel and Prince, 2001: 290-292). This lifestyle may have afforded the numerous tribes assembling these populations to reach their full genetic potential in stature.

A study of the skeletal remains of slaves and free blacks from the First African Baptist Church Cemetery in Philadelphia, Pennsylvania was used to illustrate the impact of slavery on the health of children in the United States. Rathbun and Steckel (2002) found that the prevalence of childhood stress markers (cribra orbitalia, linear enamel hypoplasia, and shortened stature) were higher amongst the slave population. Historical documents for the free black community showed that this group may have had greater access to food as they were involved with food provisioning (Rathbun and Steckel, 2002: 220). According to Rathbun and Steckel (2002), children labelled as the property of slave owners displayed the shortest stature based on slave manifests. Despite these growth insults, these individuals were able to catch-up in growth (Rathbun and Steckel, 2002:220). Steckel (1983) states that catch-up growth most likely occurred during adolescence as this was the period when their diet included the consumption of raw/red meat.

The minimum height required to join the military in the United States fluctuated throughout the 18th and 19th centuries (Table 3.1). Sledzik and Sandberg (2002) wanted to assess if these minimum height requirements reflected values recorded from human skeletal remains from four sites containing soldier burials from this period.

Table 3.1: *Minimum height requirements for United States Military between the 18th and 19th centuries. Source: Billings, 1875 in Sledzik and Sandberg (2002) p.201.*

Period	**Minimum Height**	**Branch**
AD 1790	167 cm	Whole Military
Mexican American War (AD 1846-1848)	160 cm	Whole Military
AD 1854	164 cm	Whole Military
AD 1874	164 cm	Infantry and Artillery
	165 cm to 177 cm	Calvary

Overall, the human skeletal material recovered from Fort Laurens, Snake Hill, Glorieta Pass, and Little Bighorn demonstrate a tall stature (average of 173.4 cm- 5’8”) and little evidence of childhood stress. It is after this period when male stature increased by seven cm (169 cm to 176 cm) due to the improvement in sanitation after the industrial period in America between AD 1890 and AD 1930 (Steckel, 2012:233-234).

3.2.6.2 Europe

There was a general increase in stature in the 19th and 20th centuries in Europe, especially after World War II (Cole, 2003) of approximately one centimetre per decade between AD 1880 and 1980 (Eveleth and Tanner, 1990), which has been associated with better nutrition and access to health care (Steckel, 1983; Eveleth and Tanner, 1990). Various studies have looked at diachronic changes across Europe and over large periods of time. This subsection attempts to synthesize a few of these studies.

To detect fluctuations in population health in Sweden throughout the last millennium, Gustafsson and colleagues (2007) reviewed stature and sexual dimorphism between the 10th and 20th centuries. Stature remained statistically similar throughout the 10th-17th centuries, however, between the 17th and 20th centuries, stature increased by approximately 13 centimetres in male conscripts (Gustafsson *et al.*, 2007:862). This was attributed to better living conditions, as there was no genetic discontinuity during this period (Gustafsson *et al.*, 2007:864). Cardoso and Gomes (2009) similarly examined diachronic changes in stature within Portugal, from the Mesolithic to the modern periods. Unlike the sample from Sweden, a decrease in stature between the Middle Ages to the late 19th century occurred, followed by a sharp increase in stature during the 20th century. The decrease in stature was attributed to an increase in population size and urbanisation (greater chance for infection and disease as well as poor sanitation). In central Italy, Giannecchini and Moggi-Cecchi (2008) analysed over 1000 human skeletal remains dating from the Italian Iron Age to the medieval period. Stature reduced from the Iron Age to the Roman period by an average of 2.2 cm in males and 2.4 cm in females, followed by an increase in stature during the medieval period (Giannecchini and Mogg-Cecchi, 2008:288) (Fig. 3.1).

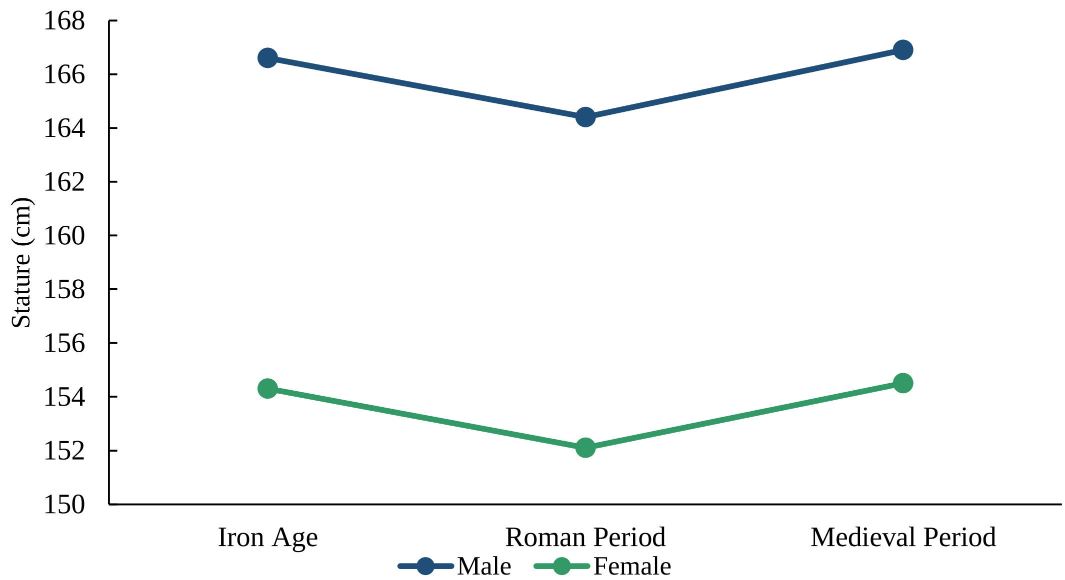


Figure 3.1: *Mean statures derived from Pearson's (1899) stature calculation of samples from Central Italy, demonstrating "U" shape trend in stature. Source: Giannecchini and Moggi-Cecchi, 2008, p. 290.*

It was suggested that socioeconomic policies during the Roman period led to the decrease in stature (Giannecchini and Moggi-Cecchi, 2008:292). These trends in stature are described as a "U" shape, with taller statures recorded prior to the Roman period followed by a recovery during the medieval period. Similar "U" shape trends occurred throughout Europe with a fall in stature followed by a period of recovery, though not all "U" shape trends occur contemporaneously throughout Europe. To further illustrate this "U" shape, Steckel (2004) reanalysed historical and bioarchaeological sources to examine diachronic trends in stature in northern Europe (Denmark, Netherlands, Norway, Iceland, Sweden, and England) during the medieval period. The average stature of northern European populations decreased between AD 1450 and 1750, followed by an increase during the industrial revolution (Fig. 3.2) (Steckel, 2004:214).

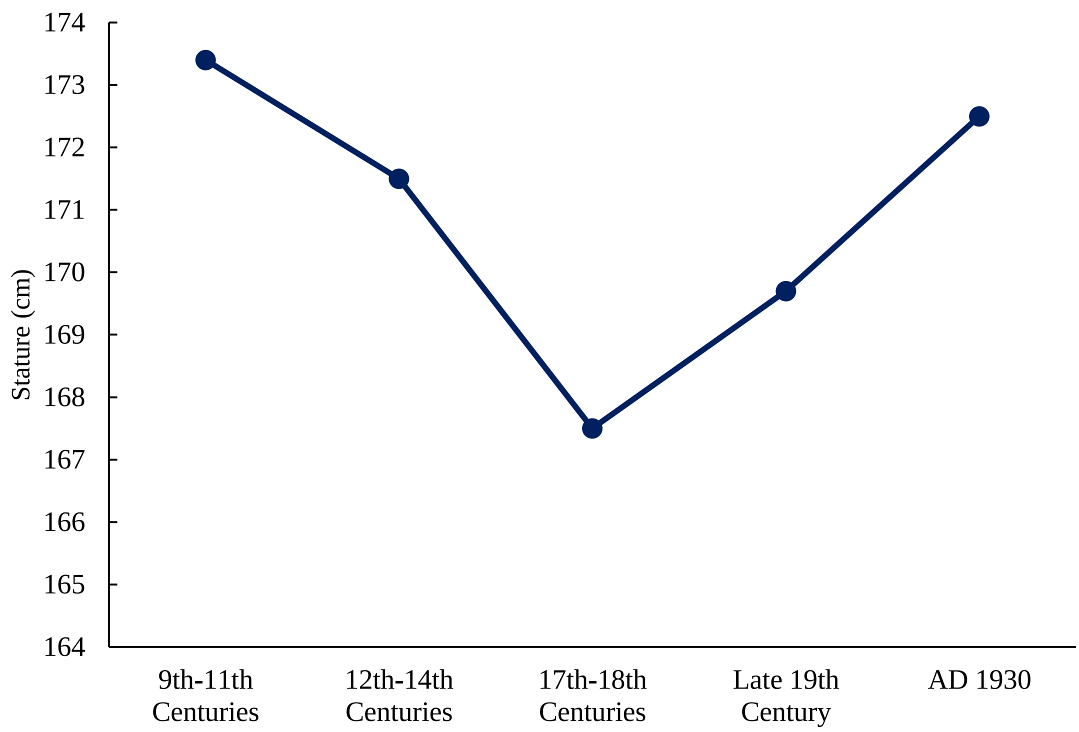


Figure 3.2: *Simple means of mean statures calculated from skeletal and historical documents of adult males from northern Europe demonstrating "U" shape trend in stature. Source: Steckel, 2004, pg.216.*

The decrease in stature experienced between AD 1450 and 1750 may be linked to "climate change, growing inequality in real income after [AD] 1500, urbanisation and growth of trade that spread diseases, wars and religious conflicts, the global spread of new varieties of disease associated with European expansion and colonisation, and population cycles" (pg. 217). Europe experienced a warm period between AD 900 and 1300 (as evidenced from ice cores and tree rings) allowing areas further north to be populated and a longer growing season thus increasing agricultural output (Fagan, 2000; Steckel, 2001).

Beginning in the 13th century, decreases in agricultural production and crop varieties resulted from the Little Ice Age (Fagan, 2000). This impacted populations throughout northern Europe, with depictions of a frozen River Thames in London in the 17th century AD (Fig. 3.3) (Steckel, 2004). Populations inhabiting the northern locations found it difficult to maintain the previous century's success in agricultural production (Steckel, 2001, 2004), therefore migration from more isolated communities increased the spread of diseases in larger cities (Steckel and Floud, 1997). Likewise, global trade also facilitated the spread of disease (Steckel, 2004:219). Steckel (2004) believes that Europeans suffered the worst health and nutrition during this period with shorter stature evident within the 17th century. Towards the end of the Little Ice Age there seems to be an increase in stature, most likely attributed to improved technology for agriculture, better nutrition, trade and networking, and a warming climate (Steckel, 2004: 221-222).

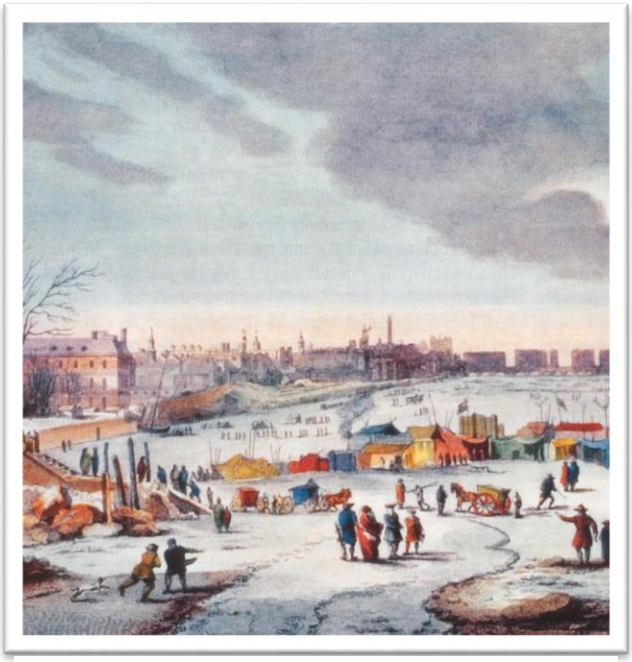


Figure 3.3: *Painting of "Thames Frost Fair, 1683-1684" Illustrated by Thomas Wyke. Image taken from Wikipedia.*

3.2.6.3 United Kingdom

In England, stature and population size slowly increased from the 1st century until about the mid-11th century (Kunitz, 1987; Roberts and Cox, 2007). Stature during the first millennium appears to be similar to stature attained during the mid-19th century despite the higher risk of mortality (Kunitz, 1987:274). Increases in the population of England occurred between the 11th and 13th centuries, after the invasion of Normans from France within the 11th century (Kunitz, 1987; Schweich, 2005; Roberts and Cox, 2007). There is a decrease in stature in Britain during this period, due to the increased spread of infection and disease, whilst the allocation of resources may have become less equal (Kunitz, 1987; Schweich, 2005; Roberts and Cox, 2007). During the 18th century AD, the Scottish were recorded as having the tallest stature in the United Kingdom with an average of 171.8 cm compared to the Irish and English averages of 167.3 cm and 167.6 cm, respectively (Steegmann, 1985: 80; Steckel, 1995). It was during this century that Parliament lowered the minimum British Standard Army standard stature to approximately 162 cm (Steegmann, 1985). There is a decrease in stature just prior to industrialisation, in which urban males are significantly shorter than rural males (Steckel, 2001). Though there was an increase in urbanisation and spread of disease during industrialisation, these negative environmental factors may have been corrected with improved nutrition from a variety of food grown locally and traded, as well as newer technologies used for harvesting plants (Steckel, 2001). Throughout the 18th and 19th centuries, individuals from Ireland and Scotland were purported to be amongst the tallest in Europe, followed by Norway, Sweden, England, France, and Austria (Steckel, 1995; Wilson, 2001:6494). However, this trend in stature shifts with those from the Netherlands experiencing a rise in stature within the 20th century, becoming the tallest population in the world today, followed by America, England, France, and Austria (Wilson, 2001).

In common with other populations across Europe, those living in what is now the United Kingdom demonstrate peaks and troughs with regard to average stature. The rise and fall of stature from the Mesolithic to Post-Medieval periods in Great Britain can be found in Table 3.2. Few studies have critically analysed stature from human skeletal remains from Britain using the revised Fully anatomical method, rather preferring to use mathematical regression formulae. Schweich's (2005) study of stature and body proportions from the Roman to Post-Medieval periods in England found the Romano-British sample to be the shortest (male average 168 cm), whilst the Early Medieval sample demonstrated the tallest stature (male average 171 cm). Schweich employed Trotter's (1970) 'white' female and male equations. Research specific to the Early Medieval period includes Härke's (1990, 1992, 2005) studies of Anglo-Saxon weapon burials. He argued that there were differences between the stature of males buried with and without weaponry, with the former being the tallest. This he linked to the burial practices of the taller 'Germanic' migrants (Härke, 1990, 1992, 2005). Stature for males dating to the Early Medieval period tend to be approximately 4 cm taller than those dating to Roman Britain (Wells, 1969:459-460; Harman *et al.*, 1981:149; Härke, 2005:201).

Table 3.2: *Mean statures for females and males throughout periods in Great Britain. Source: Roberts and Cox, 2003, pg. 396*

Period	**Females**			**Males**			**Change in Stature from Previous Period (cm)**	
	Mean (cm)	Range (cm)	*N*	Mean (cm)	Range (cm)	*N*	Female	Male
Mesolithic	157	152-162	2	165	160-168	3		
Neolithic	157	151-161	36	165	162-177	71	+0	+0
Bronze Age	161	154-161	20	172	167-177	61	+4	+7
Iron Age	162	154-164	72	168	164-174	113	+1	-4
Roman	159	150-168	1,042	169	159-178	1,296	-3	+1
Early Medieval	161	152-170	751	172	170-182	996	+2	+3
Late Medieval	159	154-165	7929	171	167-174	8494	-2	-1
Post-Medieval	160	156-164	540	171	168-174	558	+1	+0

In contradiction to the conclusions of Schweich (2005) and Härke (2005) studies, Galofré-Vilà *et al.*'s (2017) analysis of stature from the past 2000 years in England argues that stature increased during the Roman period, followed by a decrease after Roman occupation and the settlement of Anglo-Saxons (pg. 15). The authors' use Trotter and Gleser (1952) to calculate stature from femoral lengths measurements taken from the WORD database for Museum of London samples, published osteological data (many from Roberts and Cox (2003)), and Schweich's (2005) data. They found that their estimates of stature were lower than those presented by Schweich, which could be due to the use of different regression equations (Trotter and Gleser, 1952 vs Trotter, 1970). These conflicting findings highlight the need for an in-depth analysis of stature estimations for both Romano-British and Early Medieval populations.

3.3 Body Proportions

The study of body proportions in past populations is not only an examination of growth and development, stature, and general health, but has been utilized by researchers to assess diversity seen in past populations inhabiting various geographic locations (Trinkaus, 1981; Holliday, 1997a; Kurki *et al*., 2008; Auerbach, 2012), adaptation to extreme environments (Ruff *et al.*, 2002; Holliday and Hilton, 2010; Vercellotti and Piperata, 2012), examine differential growth of the body (Bogin, 2012b:349), and view changes in proportions through time (Meadows and Jantz, 1995; Jantz and Jantz, 1999; Zakrzewski, 2003; Giannecchini and Moggi-Cecchi, 2008). The body shape, size and proportions of humans tend to follow an ecogeographic pattern (Roberts, 1978; Trinkaus, 1981; Ruff, 1994; Holliday, 1997a; Auerbach and Ruff, 2010) and could indicate a population's adaptive response to climate, altitude change, and stress (Duyar and Pelin, 2003; Temple *et al.* 2008; Béguelin, 2011). Similar to stature, differences in body proportions are a combination of genetic (climatic changes), epigenetic, and environmental factors (nutrition and disease) (Ruff, 2002: 227; Bogin, 2012b:357). This section will discuss the general rules of thermoregulation in mammals and ecogeographic variation, the impact of growth and development on body proportions, and finally studies of body proportions utilizing both living and past populations.

3.3.1 Bergmann's and Allen's Rules

Homeothermic species' (humans) geographical cline has been recognized for over a century with studies conducted by Bergmann (1847) and Allen (1877) on thermoregulation in mammals. Bergmann's rule states that individuals residing in colder climates will exhibit a greater body mass than individuals from warmer climates (Beall and Steegmann, 2000; Auerbach, 2012). Individuals with a greater body mass may produce an abundant amount of heat, compared to those with low body mass. This rule of thermoregulation is one reason why bodies with greater mass are usually discovered in colder climatic regions (Ruff, 1994). Differences in body mass are detected bioarchaeologically through the measurements of bi-iliac breadth and femoral head diameter (Auerbach, 2012). One of the first studies that utilized Bergmann's rule was in the 1950s by D.F. Roberts who attempted to correlate body size with mean annual temperatures (Barker, 1990). Roberts (1978) explained that ecogeographic patterning of body proportions, size, and shape is due to adaptation to climate through the selection for beneficial genes (natural selection). Demonstrating this adaptation, a negative relationship has been discovered between sitting height (Fig. 3.4) and mean annual temperature in humans (Schell *et al.*, 2012: 247). Allen's rule states that those inhabiting colder environments will have shortened upper and lower limbs in comparison to trunk length, whilst those living in warmer environments will have elongated upper and lower limbs (Beall and Steegmann, 2000; Ruff, 2002; Temple *et al.*, 2008; Béguelin, 2011). Shortened limbs allow the body to conserve heat in colder climates as there is a decreased amount of surface area exposed per unit of body mass (Ruff, 1994, 2002; Beall and Steegmann, 2000; Temple *et al.*, 2008), whilst elongated limbs provide an increased surface area to allow the body to cool down (Ruff, 1994, 2002; Temple *et al.*, 2008). An increase in surface area is the fastest way for a body to dissipate heat according to Flourier's Law of Heat Flow (Frisancho, 1993). It is important to remember that limb length can be affected not only by thermoregulation, but by nutritional resources as well (Tanner *et al.*, 1982). This difference in limb length can be attributed to differences in proximal and distal limb segments (Trinkaus, 1981; Ruff, 1994). The surface area (Allen's Rule) to body mass (Bergmann's Rule) ratio should increase in warmer climates and decrease in cooler climates (Ruff, 1991, 1994; Temple, 2011).

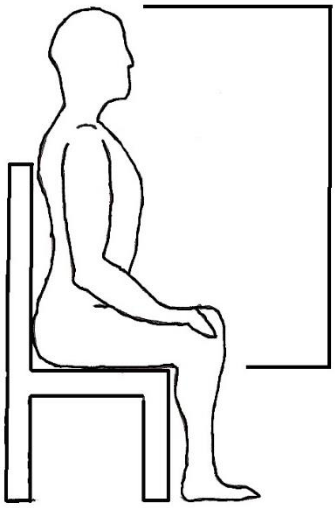


Figure 3.4: *Measurement of sitting height (cranium to pelvis). Illustration by R. Walther.*

3.3.2 Ecogeographic variation

Originally, research on geographic variation focused on cranial shape changes in early hominids and humans to detect global variation (Ruff, 1994). In the 1960s, researchers began focusing on the postcranial skeletal elements of the body (Ruff, 1994). This allowed investigators to apply Bergmann's (1847) and Allen's (1877) rules of thermoregulation to geographic patterns in humans (Ruff, 1994). Ecogeographic variation has been noted by several researchers (Ruff, 1994; Holliday, 1997a/b, 1999; Holliday and Hilton, 2010; Cowgill *et al.*, 2012). Though cultural adaptation such as the construction of shelter, clothing, and fire aid in the adaptation to an environment, certain morphological characteristics may still be advantageous (Ruff, 1991: 91). Ruff stated that "…observed geographic clines in body size and shape must be viewed as a result of *compromises* between many factors, both climatic and non-climatic. Non-climatic factors could include diet, distribution of resources, insularity, intra and interspecific competition, etc" (pg. 90). The shortening and elongation of different long bones are part of ecogeographic variation (Auerbach, 2012; Ruff *et al.*, 2012) and adaptation of the body to the local environment in terms of thermoregulation (Johnston, 1998a; Temple, 2011). According to Beall and Steegmann, "thermoregulation is a classic example of a self-regulating system managed by complex feedback loops" (2000:168).

Based on Bergmann's and Allen's rules, Ruff (1994) developed four regional categories for body shape and size for humans: sub-Saharan Africans (tropical), south eastern Asians between 45^0 and 23^0 North latitude (subtropical), Europeans (cold adapted), and northern Asian (subarctic) (pg. 73). These body proportions remain constant despite differences in stature. Some populations are extremely well adapted to their climate. Those demonstrating extreme adaptation to their environment include the Inuit in North America. This population exhibits shortened upper and lower limbs as well as wider and heavier bodies to generate and conserve heat in their cold environment (Holliday and Hilton, 2010). Based on appearance alone, African Pygmy populations may give the impression of shorter limbs and wider bodies, characteristics usually associated with higher latitude populations like the Inuit. However, when their bi-iliac breadth is compared to other African populations, they are within the range for warm adapted body proportions (Ruff, 1994).

In Ruff's (2002) analysis of worldwide variation in body size and shape, differences were detected between individuals living in higher and lower latitude locations. Limb segments and body breadth of individuals from east Africa (lower latitude) and Inuit and Aleuts (higher latitudes) were compared with differences in the ulna and bi-iliac breadth found between each population (Fig. 3.5). The upper and lower limbs have a greater surface area to mass ratio than the trunk in those from east Africa, so lengthening or shortening these appendages will increase surface area to dissipate heat in warmer climates without adding too much mass (Ruff, 1994; Holliday, 1999). The opposite is true for the Aleuts and Inuit, who demonstrated wider, heavier bodies and shortened limbs due to their colder environment. Another example of variation in body proportions include differences between African American and African populations, with African populations displaying narrower bodies and longer limbs (adaptation to expel heat and cool the body in warmer climates) (Tanner, 1989; Norgan, 1998). Those of European ancestry as well as South-eastern and Far-eastern Asian ancestry tend to demonstrate wider bodies in order to generate and conserve heat for their bodies in colder climates (Tanner, 1989; Norgan, 1998).

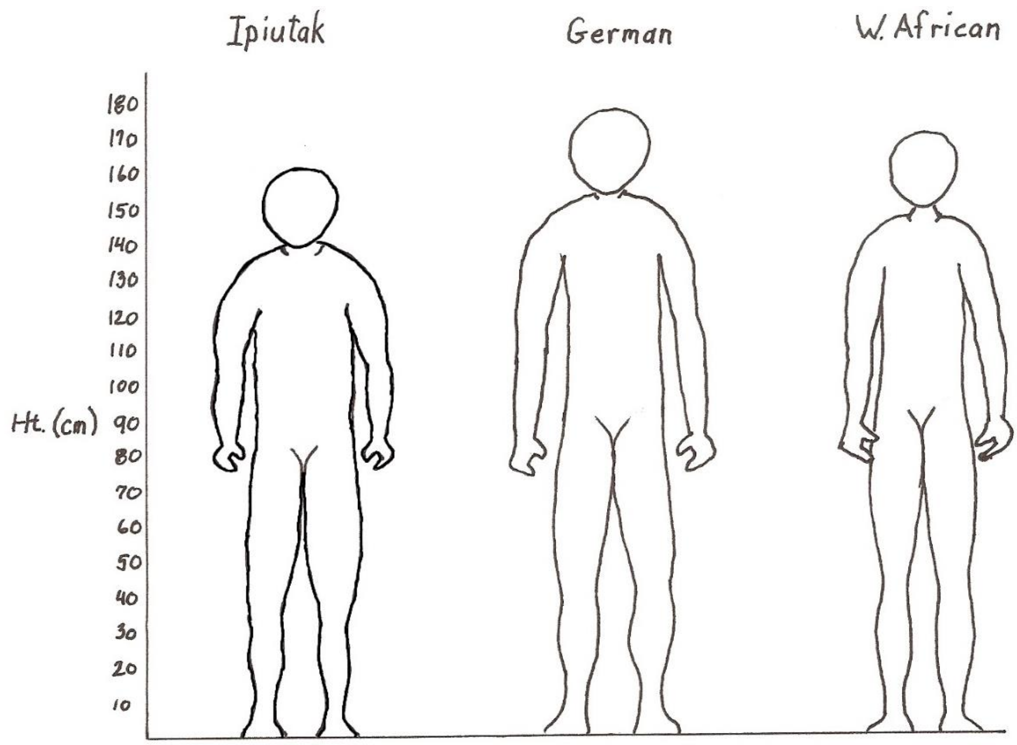


Figure 3.5: *Stature and body proportions of adult males with 'cold-adapted' and 'warm-adapted' proportions. Ipiutak male presents a 'cold-adapted' body with shorter stature, distal limb lengths (radius and tibia) and wider body. The West African male presents a body better adapted to a warmer climate with longer distal limbs (radius and tibia) and narrow body width. The German male presents body proportions with slightly elongated distal limbs compared to the Ipiutak and taller stature. Data on limb measurements and stature from Holliday and Hilton, 2010, p.290-291. Illustration by R.Walther.*

Other studies have discovered that increases in stature are caused by an increase in the distal segment of the lower limb (tibia) (Meadow and Jantz, 1995; Jantz and Jantz, 1999). There seems to be a latitudinal variation in the length of the tibia with those residing in lower latitudes possessing longer tibiae compared to those in higher latitude regions (Ruff, 1994). This trend can also be detected in northern and southern Europe with those residing in the southern region of Europe tending to have slightly longer tibiae than individuals from northern Europe (Ruff *et al.*, 2012). This trend of elongation in the tibia has been detected through time (Niskanen *et al.*, 2013). One factor other than surface area that may affect length of the limbs is that the distal segments of the limbs have a higher density of sweat glands (Frisancho, 1993), so the longer the distal segment, the more heat can be dissipated. This added adaptation may be a reason why there are large variations in the lengths of the distal limb segments.

In their analysis of long bone lengths of individuals born in the United States between AD 1800 and 1970, Jantz and Jantz (1999) discovered that the lower limbs demonstrated a greater increase in length than the upper limbs after a bout of stress. When assessing which particular bones displayed the greatest amount of growth after a recovery from stress, the tibia and fibula were found to increase in length at a faster rate than the femur (pg. 61). Other studies demonstrated similar results with the lower limb length increasing more than other areas of the body, such as the trunk or upper limbs (Gunnell *et al.*, 1998; Bogin *et al.*, 2002; Dangour *et al.*, 2002). These skeletal elements also demonstrate a faster rate-of-change when exposed to a new climatic environment, as seen in New World samples (Auerbach, 2007). The distal segments of the limbs are more variable and most sensitive to environmental change (Holliday, 1997a, 1999; Jantz and Jantz, 1999; Holliday and Ruff, 2001; Bogin *et al.*, 2002; Temple *et al.* 2008; Ruff *et al.*, 2012), which could be one of the causes of worldwide variation in body proportions (Holliday and Ruff, 2001). During the past 100 years in Japan, females and males experienced an increase in stature, mostly caused by an increase in lower limb length due to changing nutrition (Eveleth and Tanner, 1990; Ruff, 1994; Norgan, 1998). Interestingly, limbs do not demonstrate a strong correlation between limb length and ecogeographic variation in lower latitude locations. Sub-optimal nutrition due to poor diet during growth and development could shorten limbs and therefore impact final long bone lengths, not allowing an individual to reach their full genetic potential (Ruff, 1994). This is demonstrated in Pomeroy and colleagues' (2012) study of limb lengths in Peruvian children residing in different environments, where the greatest population differences in limb length occurred within the tibia (pg. 7). The sensitivity to environmental change of the distal segments of limbs is observed more in males than in females (Holliday and Ruff, 2001). Females demonstrate equal variance between the proximal and distal segments in both the upper and lower limbs, whilst males demonstrate a greater variance in the lower limb, meaning that the tibia is more variable in length than the femur (Holliday and Ruff, 2001). There is less ecogeographic variation in the upper limb than the lower limb (Ruff *et al.*, 2012). Distal segments of limbs are longer when compared to proximal segments in warmer climates (Roberts, 1978).

3.3.3 Impact of ontogeny on body proportions

Differences in intralimb body proportions due to ecogeographic variation is evident not only in adult proportions, but in the proportions of children (Cowgill *et al.*, 2012). In Cowgill and colleagues' (2012) study of non-adult human skeletal remains it was discovered that brachial and crural indices remained similar in childhood and adulthood. The authors hypothesised that these indices remain similar throughout ontogeny (pg. 557). Throughout the infant growth period individuals seem more susceptible to cold stress than during other periods of growth (Cowgill *et al.*, 2012). During development, the proportion of lower limb length in comparison to stature increases (Bogin, 2012b:349-350). The earlier development of the femur compared to other skeletal structures demonstrates its importance to growth and development as resources are allocated to continue growth of this bone at the expense of other skeletal elements (Gasser *et al.*, 1991). Skeletal elements with the fastest growth are usually the most affected by nutritional deficiencies (Cowgill *et al.*, 2012). For example, long bones of the lower limbs, especially the tibia, experience a high velocity in growth between birth and seven years; therefore a shortened lower limb length could indicate a period of stress in infancy or childhood (Bogin, 2012b:357). One of the first to recognize a correlation in childhood health and the ratio of lower limb length to total stature was Isabella Leitch (Bogin, 2012b: 358). In her study, children with longer lower limbs were less susceptible to contracting bronchitis (Leitch, 1951). Many studies corroborate these results with increasing length of the lower limbs corresponding to improved nutrition, environment, socioeconomic status and overall health (Bogin, 2012b: 359).

Due to differences in the velocity and time spent growing and developing between females and males, sexual dimorphism has been discovered not only in stature (Section 3.2), but in the proportions of sitting height and leg length (Tanner 1962; Hauspie and Roelants, 2012:72). Though leg length has been purported to be a sexually dimorphic trait, it does not become so until adolescence. No statistically significant differences in the length of long bones was detected between females and males in the Denver Growth Study at the age of ten years, however, growth during adolescence leads to significant differences by the age of 16 years (Smith and Buschang, 2005:734). With regard to the length of the tibia females have, on average, an 8 mm advantage at the age of ten years, the largest difference seen in any of the long bones at this age (Smith and Buschang, 2005:735). Interestingly, differences between females and males with regard to adult stature is caused not by lower limb lengths, but torso height (Tanner *et al.*, 1976:109). Relethford and colleagues' (1980) study of populations inhabiting rural western Ireland also found that sitting height decreases with age, as the compression of intervertebral discs throughout life leads to shorter torso length. Unlike torso length, lower limb length relative to total stature does not seem to change greatly throughout the ageing process (Relethford *et al.*, 1980:418).

Measurements taken from living populations differ slightly from those taken by bioarchaeologists and osteologists. To analyse body proportions in archaeological populations, the shape and size of various skeletal elements must be taken and different indices must be utilized. The most commonly used indices to assess body proportions include brachial (radius/humerus), crural (tibia/femur), intermembral, and humerofemoral indices, along with sitting height. More recent measurements used to assess body mass and shape include measurements of bi-iliac breadth in the ilium and femoral head diameter in the femur (Jungers, 1985; Holliday and Ruff, 2001). These indices are used to indicate possible ecogeographic patterns with those possessing low brachial and crural indices residing in colder climate areas, whilst those displaying higher indices tend to reside in warmer climates (Trinkaus, 1981; Harrison, 1990; Holliday and Ruff, 2001; Béguelin, 2011).

3.3.4. Early hominid ancestors

Many studies have analysed changes in the body proportions of early hominids to investigate migration theories in human evolution along with climatic adaptations of different species to new and sometimes extreme environments. Since body proportions are under more genetic control than stature, longer periods of time are needed to change limb proportions to adjust for climatic changes (Ruff, 1994; Holliday 1997b, 1999; Auerbach, 2007). Over two million years ago an increase in body size between the *Australopithecines* and early *Homo* species occurred, with a greater increase in body mass in those species inhabiting higher latitude locations (Ruff, 2002). It is hypothesised that this increase was caused by the need to create and conserve more body heat (Bergmann's and Allen's Rule) (Ruff, 2002). Species living during the Middle and Early Late Pleistocene (781,000-12,000 BP) were much larger overall than modern humans, which could be caused by climatic conditions experienced by these species at that time (Ruff, 2002). Around 50,000 years ago, researchers detected a decrease in body mass in hominid ancestors through osteological analysis of the skeletal remains, though those inhabiting higher latitude regions continued to exhibit greater body mass (Ruff, 2002) than those in lower latitude locations. Ruff (2002) lists improved technology, nutrition, warmer climate, and reduced gene flow for the selection of smaller bodied humans (pg. 216). Evolutionarily, modern humans display longer lower limb lengths when compared to upper limb lengths than non-human primates and early human ancestors (Bogin, 2012b:348). These differences in body proportions in humans allow for bipedality along with several other activities including thermoregulation in more tropical environments, carrying objects with upper limbs, long distance running, and communication (Bogin, 2012b:349).

Trinkaus (1980) performed one of the first studies of body proportions in Neanderthals discovering similar proportions to modern humans with regard to limb size and robusticity. Neanderthal remains were compared to recent humans from Europe, North America, and North Africa. Tibial length ratio of Neanderthals was significantly different when compared to modern humans in North Africa (Trinkaus, 1980). The difference in tibial length between these two populations was great due to the different climates: Neanderthals in a colder European climate and North Africans in a more temperate climate. In 1981, Trinkaus stated that Neanderthals were hyper-adaptive to their cold environment, exhibiting extremely shortened distal segments of both the upper and lower limbs. They exhibit shorter radii than humans based on their brachial index and their tibiae were considerably shorter than modern humans regardless of overall size (Trinkaus, 1981). When Neanderthals' brachial and crural indices were compared to modern populations around the world, they fell close to the

Inuit and European clusters. Holliday's (1997b) more recent assessment of Neanderthal body proportions in comparison with modern populations exemplifies Neanderthals extreme cold adaptation ("hyper-polar"), possibly related also to their lack of detectable cultural adaptation to the extreme cold (Holliday, 1997b).

Ruff's (1994) study discovered that body proportions of European and Near East Neanderthals and early modern *Homo sapiens* differed, with those inhabiting Europe displaying wider bodies and shorter distal limb segments. These proportions demonstrate the slow adaptation to the colder environment of Europe (Ruff, 1994; Holliday 1997b). Shortened distal segments of the upper limb were seen only in Neanderthals inhabiting Europe (Ruff *et al.*, 2002). Measurements of bi-iliac breadth may be a better indicator of cold adaptation than limb proportions because body width is less susceptible to nutritional deficiencies (Holliday and Hilton, 2010; Ruff *et al.*, 2002).

Auerbach's (2012) analysis of early Holocene human skeletal remains from North America demonstrated that males exhibit heavier and wider bodies than Old World populations. At the beginning of the Holocene, humans were not morphologically homogeneous and these wide body breadths may be a feature retained from human ancestors. Usually, individuals with wider body breadths and heavier body masses are discovered in higher latitude locations, however, individuals from Auerbach's study were discovered far from the Arctic in North America, indicating that these individuals' ancestors may have adapted to a colder climate at the beginning of the Holocene (Auerbach, 2012).

3.3.5 Past and living human population studies

Many researchers have expressed interest in studying body proportions of past populations to detect remnants of ancestral body proportions (Temple *et al.* 2008; Temple, 2011; Temple and Matsumura, 2011), develop new population specific formulae for past populations (Giannecchini and Moggi-Cecchi, 2008; Raxter *et al.*, 2008), and assess morphological adaptations to different environments (Ruff, 1994; Holliday and Hilton, 2010; Auerbach, 2012). As discussed, climate does play a role in the proportions humans exhibit, however, this role has lessened with advances in nutrition and increases in socioeconomic status (Katzmarzyk and Leonard, 1998). Studying the proportions of living populations allows for the investigation of the impact that growth and development and environmental stressors have on past populations. The following subsections will explore body proportions in both living and past populations and discuss possible correlations between skeletal indicators of stress and differing body proportions.

3.3.5.1 Living populations

Variation in body proportions can be seen worldwide. A modern example of variation would include sitting height ratios ranging from those displaying the longest lower limbs (Australian Aborigines) to the shortest (Peruvian females and Guatemala Maya males) (Bogin, 2012b:354). Not only can anthropometric recording of children's upper and lower limb lengths, torso height, and stature inform researchers about ecogeographic patterns, they have the potential to inform health practitioners whether health policies present positive or negative impacts on growth and development of a population (Eveleth, 2001:143). Studies of modern populations have discovered that an increase in stature is usually the result of an increase in lower limb lengths, thus lower limb length, when compared to stature, can demonstrate nutritional status during periods of growth and can also be associated with morbidity and mortality risk during adulthood (Bogin, 2012b:344).

Several studies of living populations have noted increases in lower limb length through time. Tanner *et al.* (1982) discovered that the increase in stature of the Japanese between 1957 and 1977 was caused by an increase in lower limb length and not torso length (pg. 411). At the time this study was published, the Japanese torso length compared to lower limb length was similar to those seen in northern Europeans, though their stature remained slightly shorter (Tanner *et al.*, 1982). The increase in stature in Norwegian males between AD 1921 and 1962 also occurred as a result of an average increase of 4.1 cm to lower limb length and only 1.0 cm increase in torso height over the 40 year period (Udjus, 1964). A study by Bowles's in 1932 found that between AD 1840 and 1930 an increase in lower limb length between generations of fathers and sons of Harvard graduates occurred, with the lower limb length increasing by 2.4 cm (Tanner *et al.*, 1982:411). A similar study involving only mothers and daughters on the east coast of the United States found a greater increase in torso height (1.8 cm) than lower limb length (1.1 cm) (Tanner *et al.*, 1982:411). The importance of lower limb length in final stature can be seen in a study comparing growth and development between

Patamona and Wapishana children of lowland Amazonia in Guyana and a British cohort. Dangour (2001) discovered significant differences in stature between these groups with the former two displaying shorter limb lengths, but not overall torso height (pg. 658).

In 1990, Eveleth and Tanner compared the stature and body proportions of African Americans, Australian Aborigines, Asians from Hong Kong, and Europeans from Bergen, Norway, focusing on the length of the lower limbs. They discovered that African Americans and Australian Aborigines have the longest lower limbs when compared to Europeans and Asians. Though Australian Aborigines and African Americans were believed to have spent their childhood and adolescence within lower socioeconomic classes and presented shorter stature, they displayed the longest lower limb length of all populations studied. This led Eveleth and Tanner (1990) to suggest that body proportions were under greater genetic control than stature. However, a number of more recent studies imply otherwise. Bogin and colleagues' (2002) examination of growth and development in Maya American children, Frisancho *et al.*'s (2001) study of Mexican Americans living in higher socioeconomic classes, and Dangour's (2001) study of Amerindian children living in Guyana demonstrate greater stature due to better living conditions. These studies discovered that those living in higher socioeconomic classes had greater stature and that this increase was caused by an increase in lower limb length (femur and tibia) (pg.753-754), thus proportionality of lower limbs may be more affected by environmental fluctuations.

In 1999, Jantz and Jantz analysed long bone lengths of United States individuals between the years of 1800 and 1970, to detect any changes in long bone length and proportions over time. Males demonstrated greater changes than females, lower limb proportions altered more through time than the upper limbs, and distal segments (especially from the lower limbs) were more variable than proximal segments (pg.57). White male femora changed more through time than any other group and were shorter compared to black males in this study, however black males and females demonstrated shorter humeral length than white males and females. There is a decline in lower limb length during the industrial period of America, followed by a recovery with increasing lengths in the early 20th century AD. This increase in length is most likely attributed to improved sanitation and overall health (Jantz and Jantz, 1999:65).

Another study spanning ancient to modern populations was conducted by Shin and colleagues (2012) for ancient and modern Korean populations. Stature was found to have remained fairly consistent until the 20th century, when male stature increased from 161.4 to 173.2 cm and female stature increased from 147.5 centimetres to 160.1 centimetres (Shin *et al.*, 2012:436). This dramatic increase is likely to be the result of access to different nutritional and environmental resources (Shin *et al.*, 2012). Other studies of modern Asian populations have likewise highlighted increases in stature and interestingly these have largely been caused by increases in the length of the lower limb, especially the tibia (Eveleth and Tanner, 1990; Ruff, 1994; Norgan, 1998).

3.3.5.2 Archaeological populations

Investigations of body proportions are not only relevant to the study of modern populations, but can be informative in the study of past population health. Raxter and colleagues' (2008) study of Ancient Egyptian stature and body proportions revealed that Ancient Egyptians presented longer distal segments compared to limb length than American whites. Their body proportions were reported to be between those of American whites and American blacks (Raxter *et al.*, 2008)**.** Due to the variations in body proportions between the Ancient Egyptians and reference populations from which the regression formulae were derived, new regression formulae were created. The following sections will describe recent studies analysing body proportions in various past populations.

Scuilli *et al.* (1990) used different indices to examine body proportions of Native American remains from the Ohio River Valley. The Trotter and Gleser (1958) mathematical regression formulae overestimated stature in this skeletal population. This was attributed to high cormic (lower limb length relative to thigh length) and crural (leg length relative to thigh length) indices. In Auerbach and Ruff's (2010) study of numerous past populations in North America, differing body proportions were discovered based on geographic regions. Those inhabiting areas east of the Mississippi River tend to have relatively longer lower long bone lengths (Auerbach and Ruff, 2010). Giannecchini and Moggi-Cecchi (2008) detected differences in limb length between the Iron Age Italian and Roman populations, with greater changes seen in the radius and tibia than the humerus and femur. A marked increase in the length of the limbs from the Roman to the Medieval period in both males and females was also observed.

The effects of high altitude on stature and body proportions have been studied in a Prehispanic population in central Patagonia in Chile (Béguelin, 2011). Through the analysis of different indices it was discovered that Patagonians had shorter trunks along with shorter proximal segments of the upper and lower limbs, though their limbs tend to be longer than those seen in white populations in the United States (Béguelin, 2011). This demonstrates more cold adapted bodies due to the decrease in annual temperatures caused by the higher altitude, along with the higher latitude location.

When analysing human skeletal material from past populations, it is important to consider other adverse conditions, especially when comparing stature within and between populations. Several studies use skeletal stress markers of cribra orbitalia and linear enamel hypoplasia in conjunction with adult stature to assess overall health throughout childhood. (Lukas *et al.*, 2001; Goodman and Martin, 2002; Sciulli and Oberly, 2002; Pinhasi *et al.*, 2006; Temple, 2008; Schillaci *et al*, 2011). In Schillaci *et al.* (2011), an association between linear enamel hypoplasia and shortened diaphyseal length in non-adults was observed. Temple (2008) found no correlation between shortened stature or impact on limb proportions and the presence of linear enamel hypoplasia. However, according to Pinhasi and colleagues (2011), the variation in these results is not surprising as these are non-specific indicators of stress and have multiple aetologies which may impact skeletal growth differently. In the analysis of 469 individual from the Southern Great Lakes and Upper Ohio Valley regions in the United States, Sciulli and Oberly (2002) discovered an association between individuals displaying linear enamel hypoplasia and growth disturbances in both children and adults. These studies relay the importance of considering the whole individual rather than specific pathologies.

3.3.6 New techniques to analyse body proportions

Due to the differences in body proportions, especially in long bones of the lower limb, Auerbach and Ruff (2010) recommended dividing groups based on the crural index (combination of femur and tibia length compared to stature). Auerbach and Ruff (2004) postulated that the crural index could indicate whether certain regression formulae would produce accurate predicted living stature compared to other formulae. In Auerbach and Ruff’s (2010) study, four general groups with different crural indices were detected based on ecogeographic variations; high latitude, Arctic, general temperate, and Great Plains. (pg.190). They suggest using the crural indices to determine which region the study sample most likely falls under and then using mathematical regression formulae closest to that region to calculate stature (Auerbach and Ruff, 2010).

Though such indices are a useful tool to detect differences in body proportions in past populations, Holliday and Ruff (2001) recommend not just analysing the index, but assessing where the changes in the index are occurring. Individuals who have a high brachial index will either have an elongated radius or shortened humerus (pg.26). It is important to recognize where this change occurs due to the effects environment has on growth and development of the long bones. Distal segments seem to be affected by environmental changes more greatly than proximal segments, so changes in distal segments of upper or lower limbs could indicate environmental stress experienced by individuals during different periods of history, elucidating a greater picture of past health.

3.4 Chapter Summary

The combination of stature and body proportion analyses has the potential to inform researchers of not only the overall health of survivors (adults) in a population, but could elucidate possible periods of disturbances during various growth periods throughout development. Changes in stature through time can indicate improved or deteriorated environmental conditions caused by a variety of processes including nutritional resources or climate change. The assessment of stature using the Fully anatomical method provides a direct way of estimating stature, providing greater insight into the previously documented changes in stature between time and geography. When the Fully anatomical method is employed to estimate stature, researchers have the ability to utilize measurements of the torso to include in different assessments of body proportions. Evidence from past and living populations have discovered that increases in distal segment length occur in populations recovering from a period of stress. In applying various indices, shortened or elongated body proportions, especially distal segments, could represent improved environment or slow adaptation to an environment with different climates. When these two analyses are combined with stress indicators such as cribra orbitalia or dental enamel hypoplasia it multiplies the lines of evidence bioarchaeologists can use to assess health in a skeletal population.

Chapter Four: Materials

4.1 Introduction

This chapter aims to provide contextual information for the skeletal remains analysed (Fig. 4.1). It summarises the larger archaeological sites examined, such as Roman London and the Roman Suburbs of Winchester, as well as details on each cemetery excavation from published material. The total number of inhumations recovered from each site, along with the number of individuals analysed for this study are presented.

At the outset of data collection, the intention was to record as large a sample of Roman and Early Medieval skeletal remains from Britain as possible in order to address the primary aims and research questions. This initially involved the collation of cemetery sites from published and grey literature data. From this database, a number of criteria were established prior to the sites being included for primary data analysis.

1) The cemetery must contain numerous, well-preserved, adult human skeletal remains. This was essential as the more well-preserved skeletons available increased the probability of discovering skeletons with all of the necessary elements for implementing the Fully anatomical method in calculating stature.
2) The human skeletal remains had to be available for study, i.e. not reburied or embargoed. Unfortunately, the well studied Romano-British cemetery at Lankhills was unavailable to researchers during the time of data collection.
3) Osteological information (such as sex and age) were available to aid in the process of identifying appropriate skeletons prior to arrival at each museum. Sex and age estimations from published material were quickly reassessed by the author once at the museum in order to ensure correct assignation to these categories (see section 5.3, Chapter Five for details).
4) In order to finish data collection in the alloted one year time frame, sufficient time with each collection needed to be facilitated by museum curators. With current constraints on regional museum resources, this was not always possible.

The archaeological sites presented in this study represent a biased sample, both in terms of period and geographic location. Within both periods, the presence of cremated burials needs to be addressed. Cremated bone was excluded from this study as it is often too distorted and fragmented due to the burning process to assess stature and body proportions (McKinley, 1994). During the early period of Roman occupation of Britain, the predominant burial rite was cremation and therefore most Romano-British inhumed remains date to the third and, more particularly, the fourth centuries AD (Pearce, 2013). There are some well-known exceptions and Roman London, for example, has a number of sites with inhumations dating to the 1st century AD. The majority of the 'Roman' data-set is however, from the later period of Roman occupation. Similarly, cremation and inhumation co-occurred during the Early Medieval period in England and often within the same cemetery (Lucy, 2000). Though cremation was mostly practiced in East Anglia, cremation burials are now being discovered in both northern and southern areas of Britain (Lucy, 2000:140). The fact that cremation was mostly practiced in eastern England during the 5th-7th centuries the cemeteries analysed from East Anglia date to a later period (i.e. 8th-9th centuries) (see sections 4.3.12 and 4.3.13, this chapter). These two cemeteries were included so those within eastern region of the country were represented, as well as to detect any changes in stature and/or body proportions following the 5-7th centuries.

The need for cemetery sites with large, well-preserved samples presented biases. Generally, those with greater numbers of inhumations from the Roman period are from 'urban' settlements. This could present issues when comparing stature and body proportions between the Roman and Early Medieval periods, as the latter is characterised by smaller, 'rural' settlements. However, studies have found that some of the Roman 'urban' cemetery populations may have included those from the 'urban periphery' (Goodman, 2006:1-2) and rural migrants (Pitts and Griffin, 2012; Redfern *et al.*, 2015). Individuals buried within these cemeteries may not be exclusively from urban settlements, therefore their comparisons with Early Medieval cemeteries may not be an 'urban versus rural' argument. Furthermore, the simple fact is that there are not directly comparative urban sites from the Early Medieval period. However, urban connurbations in Roman Birtain are generally not what we would considred 'cities' today and were generally small towns with migration to and from the surrounding countryside as well as further afield. The lack of direct contextual equivalents across periods should not therefore overshadow any temporal trends.

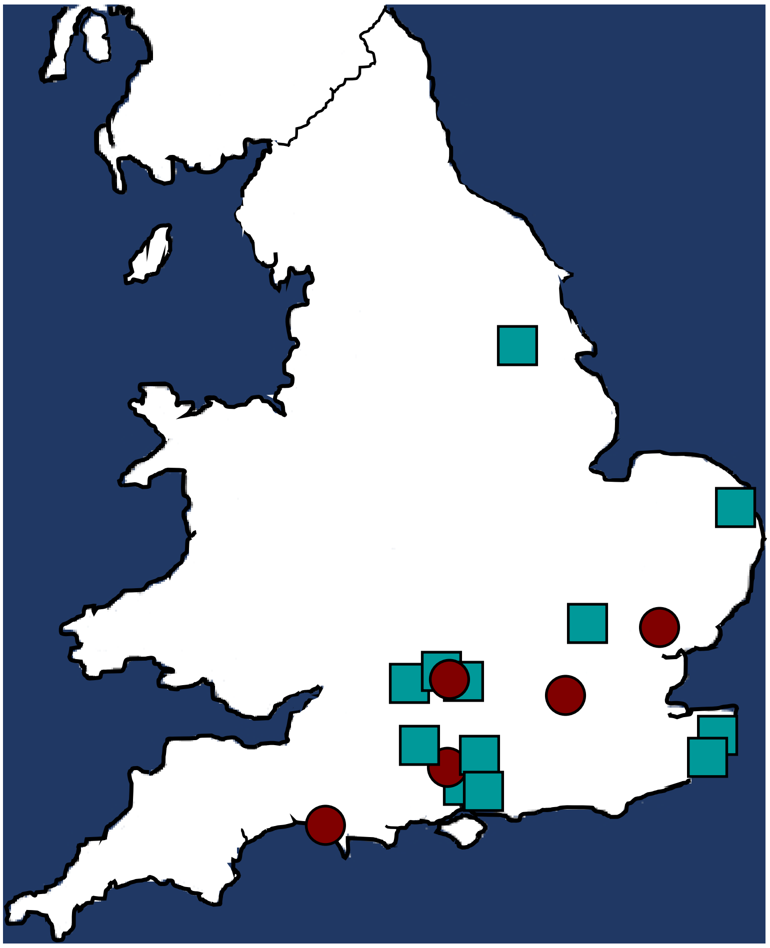


Figure 4.1: *Map of archaeological sites examined within this thesis. Red circles represent Romano-British sites and blue squares represent Early Medieval sites recorded. Source: Author.*

4.2 Romano-British Archaeological Sites

4.2.1 Roman London

The sample from Roman London includes burials from the four major cemeteries (western, southern, eastern, and northern) surrounding the ancient city of *Londinium* (Fig. 4.2). The first publication of Roman London burials was produced by the Royal Commission on Historical Monuments (England) in 1928 (RCHM, 1928). The majority of items listed in this volume, however, concern grave assemblages (Barber and Hall, 2000). Most of the information regarding human skeletal remains comes from recent excavations carried out by contract archaeologists from the 1970s onward (Hall, 1996).

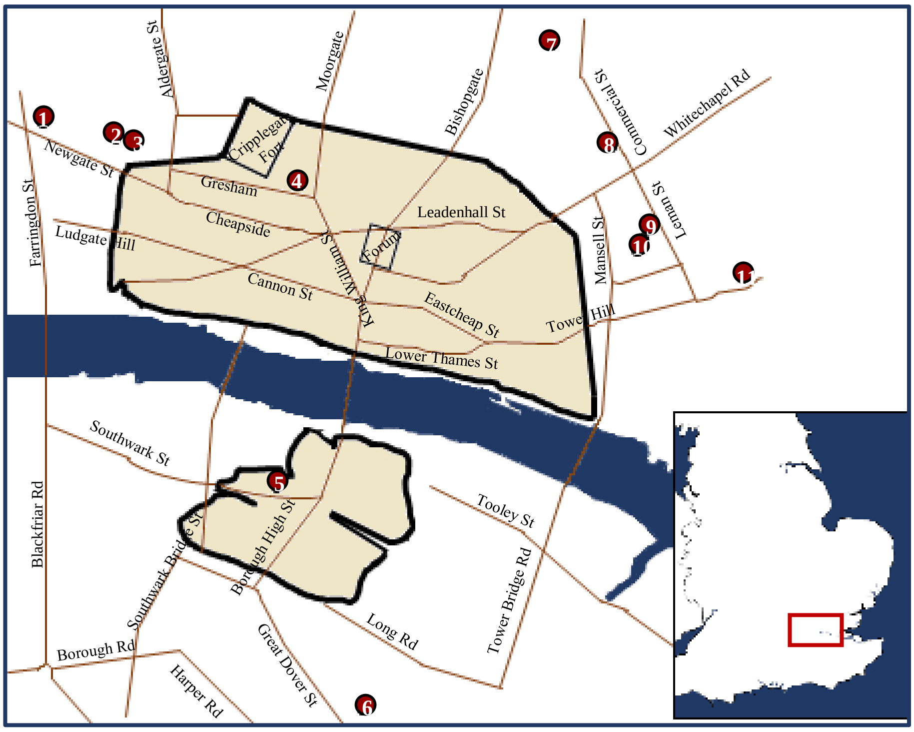


Figure 4.2: *Map presenting all Roman London sites analysed for this thesis. The black outlines and cream colour represent the city of Londinium (Roman London). Note that the majority of sites lie outside city walls. See Table 4.1 for site codes. Source: Author*

The Roman city of *Londinium* was founded shortly after Roman occupation (Watson, 2003), with the earliest coins dating between AD 50 and AD 55 (Schofield and Maloney, 1998). After the Boudican rebellion in the 1st century AD, expansion of the city began and continued throughout the 2nd Century AD (Perring and Roskams, 1991; Schofield and Maloney, 1998), growing to 395 acres (159.85 ha) with a population of up to 20,000 to 30,000 people (Watson, 2003). Roman law decreed that no individuals should be buried within the city walls (Robinson, 1992:162; Barber and Hall, 2000; Watson, 2003; Thomas, 2004), therefore cemeteries were constructed outside the city, alongside major roads (Watson, 2003).

Table 4.1: *Archaeological sites examine within Roman London. The context codes, cemetery location, total number of inhumations excavated, and total number analysed presented.*

Archaeological Site	**Context Codes**	**Cemetery**	**Number of Inhumations**	**Number Analysed in this Study**	**Number in Figure 4.2**
Atlantic House, London, EC2	ATL97	Western	20	7	1
St Bartholomew's Hospital, Giltspur Street	BAR79	Western	127	1	3
West Smithfield, Giltspur Street, Cock Lane	WES89	Western	19	15	2
Guildhall Art Gallery, Guildhall Yard	GYE92	Western	3	1	4
Courage Brewery, Park Street	COSE84	Southern	7	2	5
165 Great Dover Street	GDV96	Southern	25	4	6
13 Haydon Street	HAY86	Eastern	17	4	8
Hooper Street	HOO88	Eastern	103	9	11
49-55 Mansell Street	MSL87	Eastern	223	44	10
37-43 Mansell Street	MST87	Eastern	72	6	9
St Mary Spital, Spitalfields Market	SRP98	Northern	130	20	7

Despite this law, a few inhumation and cremation burials have been discovered within the ancient urban centre, however these are exceptions to the rule (Perring *et al.*, 1991). Four major cemeteries likely served Roman London and the Southwark suburb (Barber and Bowsher, 2000). Inhumations from Roman London cemeteries are similar in style to those excavated from urban populations throughout Roman Britain, usually with the deceased placed in an extended, supine position, within a wooden coffin (Philpott, 1991).

A total of 10 archaeological sites excavated throughout the late 1970s have been analysed at the Centre for Human Bioarchaeology at the Museum of London. These 10 sites represent all four cemeteries, although the number of individuals available for analysis was variable, depending upon preservation and the extent of excavation. Table 4.1 presents the 10 archaeological sites examined providing context codes, cemetery location, date excavated, and publications. The following sections will discuss each cemetery, including number of inhumations discovered, associated finds, and dates of the specific site.

4.2.1.1 The western cemetery (BAR79, WES89, ATL97, and GYE92)

The western cemetery was located in the area now known as Smithfield just outside the Roman city wall between the Roman gates of Newgate and Aldersgate (Barber and Hall, 2000) (Fig. 4.3). Its boundaries lie between Smithfield and Farringdon to the north and south, respectively, and the fort wall of Cripplegate and Holborn to the east and west, respectively (Barber and Hall, 2000). Within this cemetery cremation was the predominant rite in the 1st and early 3rd centuries AD, whilst inhumations superseded in the 3rd and 4th centuries AD (Hall, 1996).

The archaeological sites located in the western cemetery included in this thesis were St Bartholomew's Hospital on Giltspur Street (BAR79), West Smithfield and Giltspur Street (WES89), Atlantic House on the banks of the River Fleet (ATL97), and burials within London's Roman amphitheatre at Guildhall Yard (GYE92). A total of 189 inhumations were uncovered from these sites between 1979 and 1997 along with three inhumations discovered within the Guildhall Yard amphitheatre. These will be detailed below.

A total of 20 inhumations were discovered during a redevelopment project for St Bartholomew's Hospital in 1979. These burials date between the 3rd and 4th centuries AD (no earlier than AD 250) and were believed to be part of an organized urban cemetery (Bentley and Pritchard, 1982). Fourteen of these burials were found to be clustered into three groups, which Bentley and Pritchard (1982) suggest were family units. The ratio of males to females within this site was 1.25:1 (Watson, 2003).

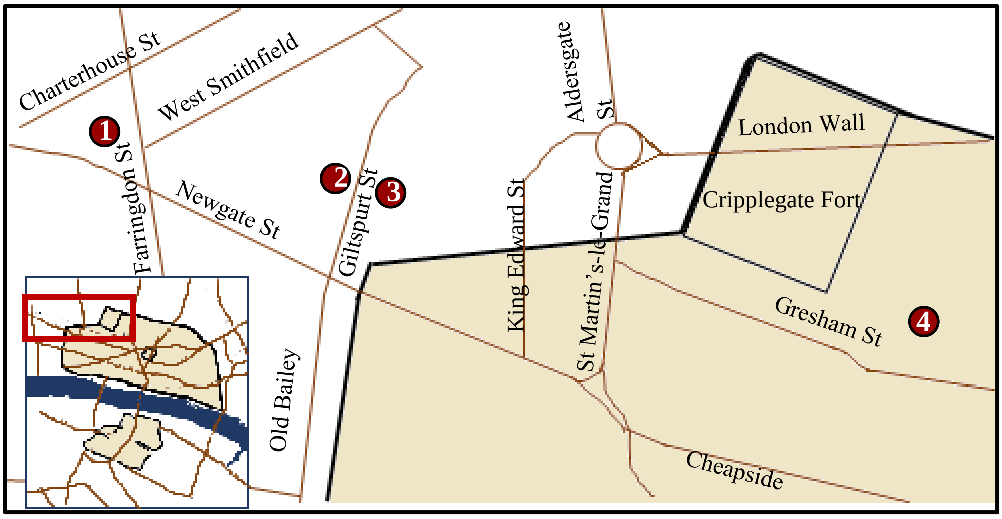


Figure 4.3: *Archaeological sites located within the western cemetery of Roman London. The bllack outline and cream colour represents Roman London's city wall. 1=Atlantic House (ATL97), 2=West Smithfield and Giltspur Street (WES89), 3=St Bartholomew's Hospital (BAR79), 4=Guildhall Yard (GYE92). Source: Author.*

Ten years later, excavations just west of St Bartholomew's Hospital revealed 127 inhumations dating to the 3rd and 4th centuries AD. Over a quarter of those buried (49 individuals) in the West Smithfield and Giltspur Street excavation contained grave goods (Hall, 1996). These included bone combs dating to the 4th century AD, a jet necklace, copper-alloy bracelets and a ring, cosmetics, and an intact Nene Valley ware coloured vessel (Shofield and Maloney, 1998:299). The presence of nails within the burials suggested the dead were buried in wooden coffins (Schofield and Maloney, 1998). The ratio of males to females was higher than at St Bartholomew's Hospital with 1.5:1 (Watson, 2003).

The final site located within the western cemetery was Atlantic House, excavated in the spring and summer of 1998 by the Museum of London Archaeology Services (MoLAS). A total of 19 inhumations were discovered with evidence of cremations on the site dating to the 1st and 2nd centuries AD, followed by a change in burial practices with inhumations during the late 2nd and 3rd centuries AD and abandonment in the 4th century AD (Watson, 2003:9). This site was similar to those found in the West Smithfield and Giltspur Street excavation (WES89) and St Bartholomew's Hospital excavation (BAR79) (Watson, 2003). The ratio of males to females was the highest of all three sites with 1.8:1 (Watson, 2003).

Finally, three burials were discovered within the Roman amphitheatre excavated between 1992 and 1998 located in the north-west corner of Londinium and do not seem to be connected or hint at a larger cemetery (Bateman et al., 2008). Activity at this site occurred as early as the mid-1st century AD with a timber amphitheatre structure dating after AD 70, followed by reconstruction and remodelling of the structure in AD 120 and AD 250-70 (Bateman et al., 2008). These three individuals, all between the ages of 17 and 25 years of age at death, date to AD 365-420, after the abandonment of the amphitheatre (Bateman et al., 2008: 92).

4.2.1.2 The southern cemetery (COSE84 and GDV96)

Very few human skeletal remains recovered from archaeological investigations within the southern cemetery were available for inclusion in this thesis. Two of the main archaeological sites included were the human skeletal remains from the excavation of the Courage Brewery bottling plant between 1974 and 1990 (Cowan, 2003) and the excavation of 165 Great Dover Street in Southwark in 1996 (MacKinder, 2000) (Fig. 4.4). A more recent site at Lant Street was unearthed in 2003, however these skeletal remains were not available for analysis. Two distinct areas can be found in the cemetery; one at Stane Street and Watling Street and the other near the Southwark bridgehead road toward Lambeth (Barber and Hall, 2000:105). A total of 32 inhumations have been discovered (not including Lant Street) in the southern cemetery.

Seven inhumations dating to the 4th century AD were discovered during excavations at the Courage bottling plant within and around a previously inhabited residential building (Cowan *et al.*, 2009:70, 191). Burials were dated from pottery (AD 300-400) and a coin from AD 340s (Cowan, 2003: 72). Three of these inhumations were buried in wooden coffins with plaster or chalk and two of the inhumations contained grave goods (Cowan et al., 2009:251-252).

The site at 165 Great Dover Street, located 1 km south of the River Thames, was more distinctive; excavations found a possible temple, two walled cemeteries, and a possible mausoleum, with activity at the cemetery beginning around AD 120-250 (MacKinder, 2000). A total of 25 inhumations were discovered from throughout the occupation of this area. According to MacKinder (2000), this cemetery may have contained high status individuals living along Watling Street just south of the River Thames.

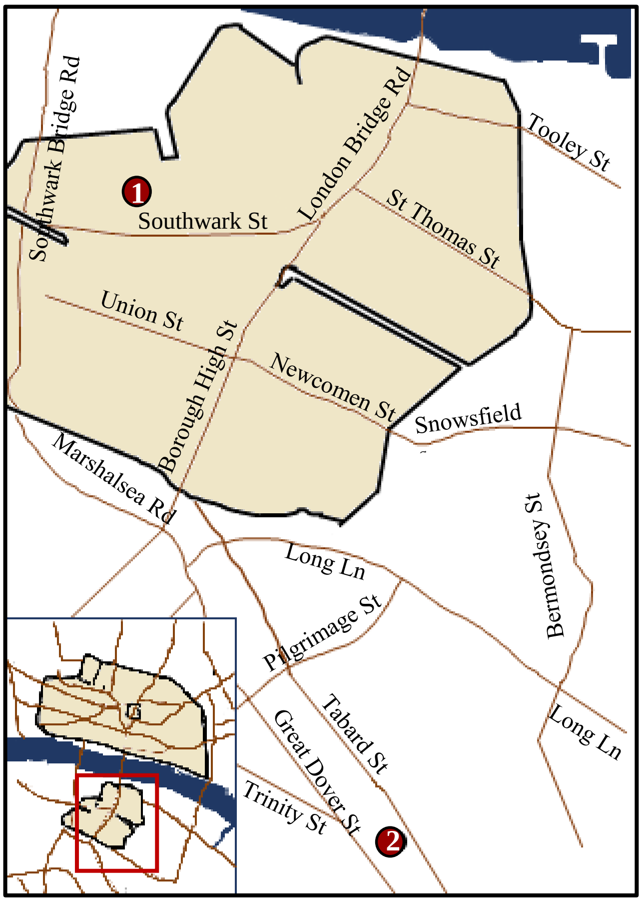


Figure 4.4: *Location of the two sites from the southern cemetery from Roman London analysed within this thesis. 1=Courage Brewery (COSE84), 2=165 Great Dover Street (GDV96). Black lines with cream shading represent Londoninium. Source: Author.*

Two phases were discovered at this site; the first phase contained a temple or mausoleum similar to others found throughout north-west Europe, with an associated group of burials, whilst the second phase included the two walled cemeteries and a possible stone mausoleum with burials inside and outside the walled structures (Hall, 1996; MacKinder, 2000). This archaeological site was unusual in Roman London as a greater number of females (seven) were identified along with six non-adults (Hall, 1996). The male to female ratio for this site was 1:1.16.

4.2.1.3 The northern cemetery (SRP98)

Continuous excavation of the northern cemetery between 1991 and 2007 at Spitalfields Market recovered 130 individuals (85 adults and 42 non-adults) (Museum of London Archive), 84 of which were discovered in 1999 (Barber and Hall, 2000). The earliest known burials discovered from this cemetery, known today as Spitalfields, was recovered in AD 1576 (Hall, 1996; Barber and Hall, 2000). This cemetery was located close to the eastern cemetery, flanking the Ermine Road leading north away from *Londinium* (Hall, 1996) (Fig. 4.5). Though the northern cemetery may lack a large number of inhumations, it has the most extensive collection of artefacts discovered from all four cemeteries (Barber and Hall, 2000). Similar to the previous two cemetery regions, the northern cemetery consisted of predominantly cremation burials in the 1st and 2nd century AD, with very few dating beyond the 3rd century AD (Hall, 1996). Inhumations located within the northern cemetery have been dated throughout Roman occupation, with evidence of this burial practice as early as AD 100, which continued in popularity in the 3rd and 4th Centuries AD (Hall, 1996).

The burials from St Mary Spital, Spitalfields Market date to the later Roman occupation of London in the 3rd and 4th centuries AD. Ten tombstones were also recovered demonstrating a civilian and military presence in the cemetery (Barber and Hall, 2000). Thomas (2004) proposed that the later burials indicated a smaller and wealthier population with over a quarter of the burials containing grave goods (pg. 28). The full report of this excavation has yet to be published.

4.2.1.4 The eastern cemetery (HAY86, MSL87, MST87, HOO88)

The eastern cemetery is situated in the modern London Borough of Tower Hamlets with 11 archaeological excavations taking place between 1983 and 1990 by the Museum of London's Department of Greater London Archaeology (DGLA) (Barber and Bowsher, 2000; Barber and Hall, 2000). This 12 hectare plot was located outside of the eastern city walls, east of Aldgate and south of the Roman road leading to Colchester (Hall, 1996; Barber and Hall, 2000) (Fig. 4.5). A total of 550 inhumations and 136 cremation burials have been excavated from the entire eastern cemetery (Barber and Bowsher, 2000; Barber and Hall, 2000). Within this cemetery only four archaeological sites have been analysed: 49-59 Mansell Street (MSL87) with 223 human skeletal remains, 7 Hooper Street (HOO88) with 103 human skeletal remains, 31-43 Mansell Street (MST87) with 72 human skeletal remains, and 13 Haydon Street (HAY86) with 17 human skeletal remains (Barber and Bowsher, 2000). These inhumations have been dated to after AD 270 and prior to AD 410 (Barber and

Bowsher, 2000). The ratio of males to females was similar to the other cemeteries with 1.7:1 (Barber and Bowsher, 2000).

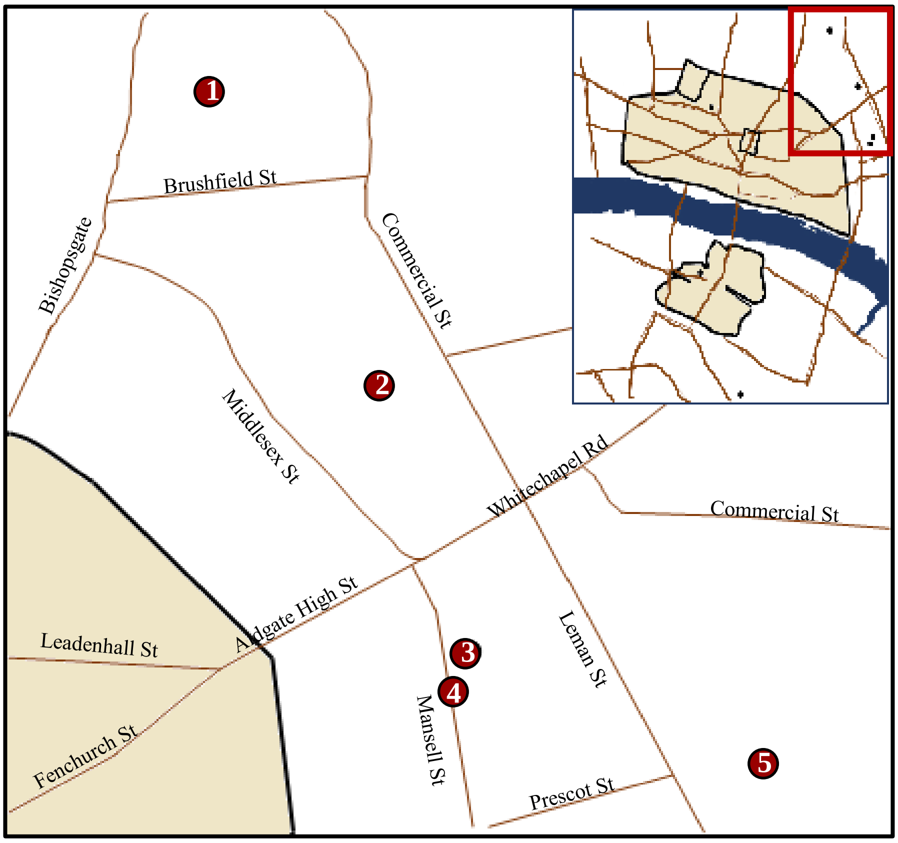


Figure 4.5: *Archaeological sites analysed within this thesis located within the northern (SRP98) and eastern cemetery in Roman London. Black lines represent the city wall. 1=Spitalfields Market (SRP98), 2=13 Haydon Street (HAY86), 3=31-43 Mansell Street (MST87) 4=49-59 Mansell Street (MSL87), 5=7 Hooper Street (HOO88). Source: Author.*

4.2.2 Roman Suburbs of Winchester, Hampshire

The Roman cemeteries of Winchester were located in the northern, eastern, and western areas located outside the Roman town of *Venta Belgarum* (Winchester) (Fig. 4.6). The city of *Venta Belgarum* was the fifth largest town or *civitas* in Roman Britain (Wacher, 1995). Excavation of the suburban areas outside of the city centre occurred in advance of the construction of roads and new housing developments between 1971 and 1986 (though the site at Andover Road in the northern cemetery was excavated in 1998). A total of 425 burials were excavated from sites within the northern, western, and eastern cemeteries (Browne, 2012:210).

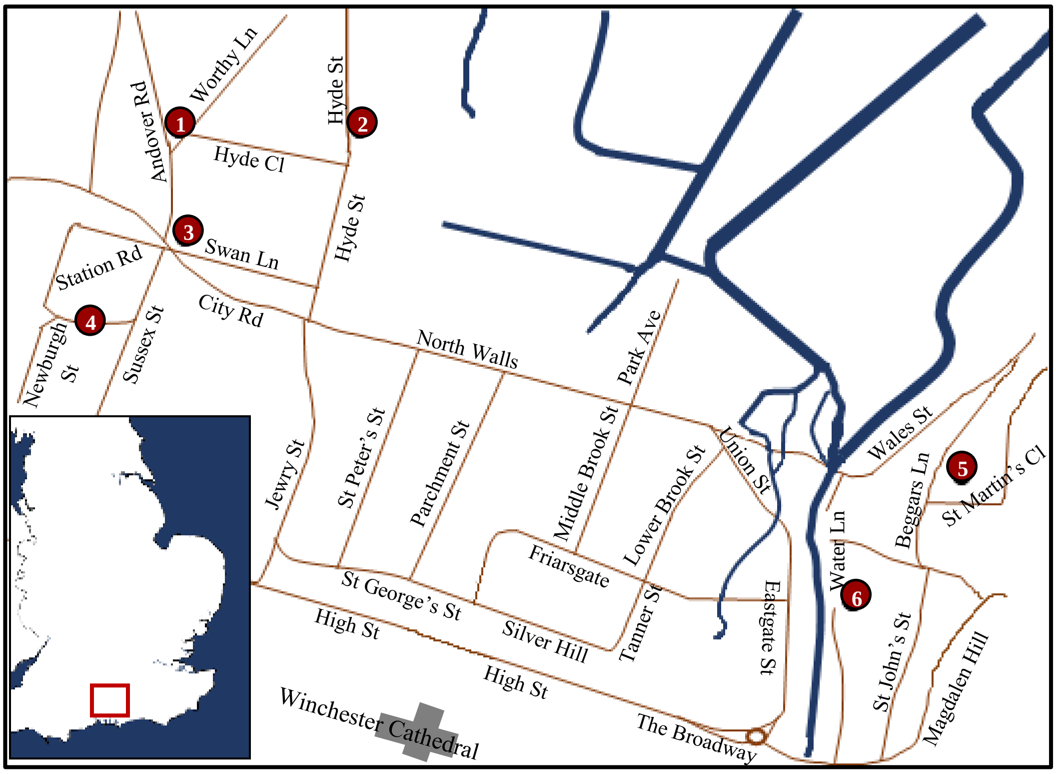


Figure 4.6: *Archaeological sites within the Roman Suburbs of Winchester. Sites within all the cemeteries (northern, western, and eastern) presented. Blue areas represent the River Itchen 1=Victoria Road East and Victoria Road West, 2=Hyde Street, 3=Andover Road, 4=Carfax, 5=St Martin's Close, 6=Chester Road. Source: Author.*

4.2.2.1 The northern cemetery (Victoria Road East, Victoria Road West, Hyde Street, and Andover Road)

The cemetery located north of the North Gate included the archaeological sites of Victoria Road East, Victoria Road West, Hyde Street, and Andover Road. Like many Roman cemeteries, this one flanked the Cirencester Road (one of the major roads leading from Winchester to Cirencester (Ottaway *et al*., 2012:19) (Fig. 4.6). The earliest portion of this cemetery was discovered at Victoria Road East as it contains burials dating between AD 50 and the mid-AD 70s. Many of the burials from this site were cremations, with only 16 inhumations present in a north-south alignment (Ottaway *et al.*, 2012). Unlike the eastern site, Victoria Road West contained the greatest number of individuals within the northern cemetery, most of which were inhumations with west-east alignment dating to the late 3rd to late 4th centuries AD. The archaeological site at Hyde Street revealed 59 graves oriented in a west-east alignment accompanied by few grave goods. This site has been dated from AD 350 to the early 5th century (Ottaway *et al.*, 2012). Finally, excavations at Andover Road in 1998 uncovered 48 graves, once again aligned west-east with some containing grave goods such as coins, bone combs, and hobnails. Andover Road seemed to be contemporaneous with Hyde Street.

4.2.2.2 The western cemetery (Carfax)

Most of the excavation that took place in the western cemetery in 1985-86 occurred within and just beyond Oram's Arbour ditch (Ottaway *et al*., 2012) (Fig. 4.6). Very little activity took place within the enclosure of Oram's Arbour, but the presence of burials indicated it might have been used as a cemetery from AD 270 to the early 5th century (Ottaway *et al*., 2012:173). A total of 35 burials were discovered, of which 26 were infants (Ottaway *et al*., 2012:173).

4.2.2.3 The eastern cemetery (Chester Road and St Martin's Close)

Two archaeological sites have been designated part of the eastern cemetery of Roman Winchester: Chester Road and St Martin's Close (Fig. 4.6). Excavations at Chester Road took place in advance of the construction of a new housing development and the discovery of 117 burials were recorded from excavations at Chester Road dating from the late 3rd to the late 4th centuries AD. Similar to other sites, graves were oriented in a west-east alignment, which occurred in 72 inhumations. A few of the graves oriented in a north-south alignment date to a slightly earlier period and this orientation seemed to fade in popularity as time progressed (Ottaway *et al.,* 2012:184). Very little was recovered with regard to grave goods from this site. The site of St Martin's Close was much smaller in scale than Chester Road with only 32 inhumations recorded. Very few inhumations contained dateable grave goods, however, it is thought that this site was in use from the late 4th or even early 5th century (Ottaway *et al.,* 2012:193).

4.2.3 Butt Road, Colchester, Essex

A large Roman cemetery was found within the modern city limits of Colchester in the county of Essex just outside the city wall of Roman Colchester (Crummy *et al.,* 1993) (Fig. 4.7). This cemetery was first recorded in the AD 1840s by amateur archaeologist William Wire, who noted a combination of cremation and inhumations from 200 burial plots (Crummy *et al.*, 1993:5). Archaeological investigation of the area was carried out by Colchester Archaeological Trust in advanced of construction of a new police building in 1976-1979 and in 1986 and 1988.

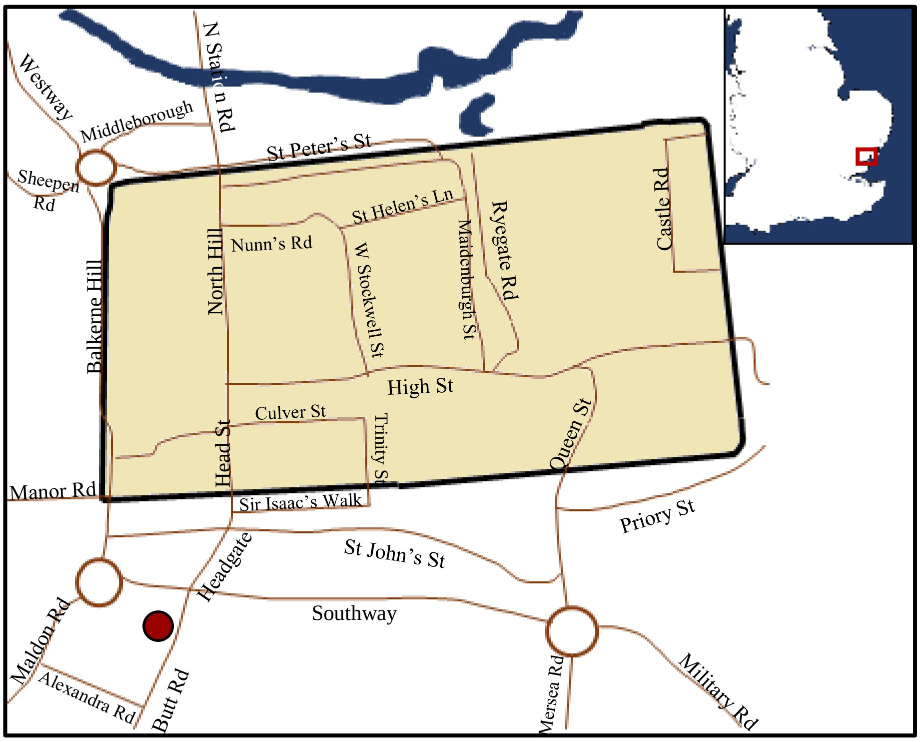


Figure 4.7*: The location of the archaeological site of Butt Road within the city of Colchester. The cream coloured area within the black lines (town walls) represent the Roman city. Blue represents the River Colne. Modern streets are outlined in brown and labelled. Note that the Butt Road cemetery is located just outside the city walls. Source: Author.*

Upon excavation two main periods of activity were discovered. The first period (Period 1) was broken into three phases dating from the 1st century until AD 320-340, whilst the second period (Period 2) dated from the mid-4th century AD (Crummy *et al.*, 1993:3). No burials were discovered within the first phase of Period 1, however 15 inhumations (including two females and four males) dated to the second phase (3rd to early-4th century AD) and 44 inhumations (including three females and five males) dated to the third phase (AD 270-340) (Crummy *et al.*, 1993:3, 14, 31). Burials from the second phase contained a few grave goods and were considered to be part of extramural land close to the town walls (Crummy *et al.*, 1993:27). Although 44 inhumations were revealed, only 23 had human skeletal remains preserved for osteological analysis.

A change in burial rite was seen within this cemetery during the transition from the third phase Period 1 burials to Period 2 burials. The majority of burials dating to

Period 2 (AD 320/40-400+) were in an east-west alignment, all of which were inhumations. A total of 669 burials were identified, of which 575 were examined (140 females and 170 males) (Crummy *et al.*, 1993:62).

4.2.4 Poundbury Camp, Dorset

Excavation at Poundbury in the north-west outskirts of Dorchester, Dorset (Fig. 4.8) revealed activity at this site dating from the Neolithic through to the Middle Ages. A total of 1400 inhumations were excavated, mostly dating to the Roman period (Farwell, 1993). Excavations continued from 1966 to 1980, with the discovery of the Late Roman cemetery during the 1973-76 excavations (Farwell, 1993:2).

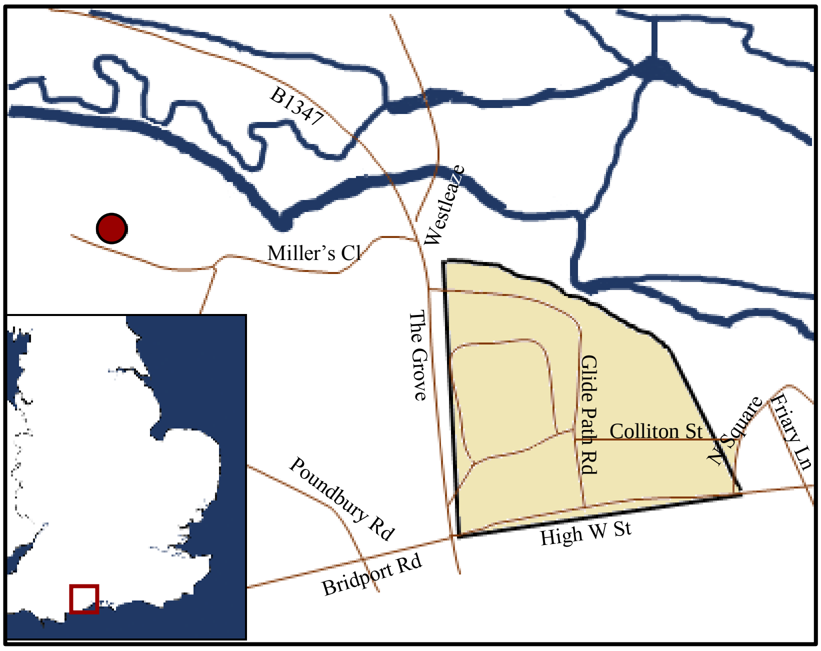


Figure 4.8: *Location of Poundbury with regard to the city of Dorchester, Dorset and the River Frome (designated in blue). Black outline represents the Roman wall of Durnovaria (Dorchester), with the cream colour representing the Roman city. Location of cemetery is highlighted with a red circle.*

Inhumations dating to the Late Roman period were divided into five groups: C Site, eastern periphery burials, northern periphery burials, outlying burials, and finally the main Late Roman cemetery (Farwell, 1993:14). Descriptions of each of the five groups is provided in Table 4.2. Overall, inhumations were west-east oriented, unaccompanied by grave goods, and females, males, and non-adults were accorded similar burial rites (Molleson, 1993:146). The different groups of burials could possibly indicate a growing population throughout the use of this cemetery, as the earliest graves display a high proportion of infant and children, followed by later burials displaying greater numbers of young and elderly adults representing a more stable population (Molleson, 1993:160). Unlike many of the Roman cemeteries found within Britain, the male to female ratio was approximately equal and there were a large numbr of non-adult remains recovered from this cemetery (Molleson, 1993).

Table 4.2: *Descriptions of the five inhumation groups from the site of Poundbury Camp. The number of inhumations excavated, number of inhumations analysed, grave orientation, and dating for each group provided. Source: Farwell, 1993.*

Burial Group	Number of Inhumations	Number of Inhumations Analysed	Orientation of Graves	Dates
Site C	101	12	West-East	Mid-4th Century AD
Eastern Periphery Burials	90	9	North-South	3rd into the 4th Centuries AD
Northern Periphery Burials	36	2	West-East	3rd and 4th Centuries AD
Outlying Burials	39	6	West-East	Contemporary with the Main Late Roman Cemetery (4th Century AD)
Main Late Roman Cemetery	1114	249	West-East	4th Century AD

4.2.5 Queensford Farm and Queensford Mill, Oxfordshire

Two separate excavations of the late-Roman cemetery of Queensford Farm and Mill located within the Upper Thames Valley 0.7 km north of the modern town of Dorchester on Thames and west of the River Thame occurred in 1972 and 1981 (Chambers, 1987) (Fig. 4.9). The first excavation of 112 burials recovered the human skeletal remains of a total of 75 individuals of both sexes and various ages-at-death (Harman *et al.,* 1979). The majority of these burials were dated to at least the 4th century AD (Harman *et al.,* 1979). In 1981, the south-western corner of the large cemetery was excavated by Oxford Archaeology Unit ahead of the construction of the

Dorchester Bypass (Chambers, 1987:35). A further 102 graves were identified with 82 excavated.

This cemetery will now be referred to as Queensford Farm/Mill for the remainder of this thesis. Chambers (1987) postulated that the cemetery served the small unnamed Roman town to the south and had the potential to contain 2,400 inhumations (p. 61). Unfortunately, a large portion of this cemetery currently remains unexcavated and damaged from gravel quarrying and road construction.

The layout of the cemetery, with graves at right angles and parallel to the cemetery boundaries (Chambers, 1987) and the intentional construction within an enclosure ditch places Queensford Farm/Mill in the 'managed' cemetery category by Booth (2001). The majority of burials were aligned west-east in a supine position with the deceased place in a wooden coffin, as evidenced by preserved iron nails (Chambers, 1987:41, 45). A large number of non-adult human skeletal remains were discovered in the cemetery, representing over a third of the population excavated from Queensford Farm/Mill (Chambers, 1987:60) with a greater number of males represented compared to females (ratio 2.9:1). Grave goods were not included with the burials, however a bone comb was discovered in one of the female burials near the head, indicating that it was worn (Chambers, 1987; Booth, 2001). New calibrated radiocarbon dates from five graves ranged in date from AD 240 to 531 at 95% confidence level (Hills and O'Connell, 2009:1101).

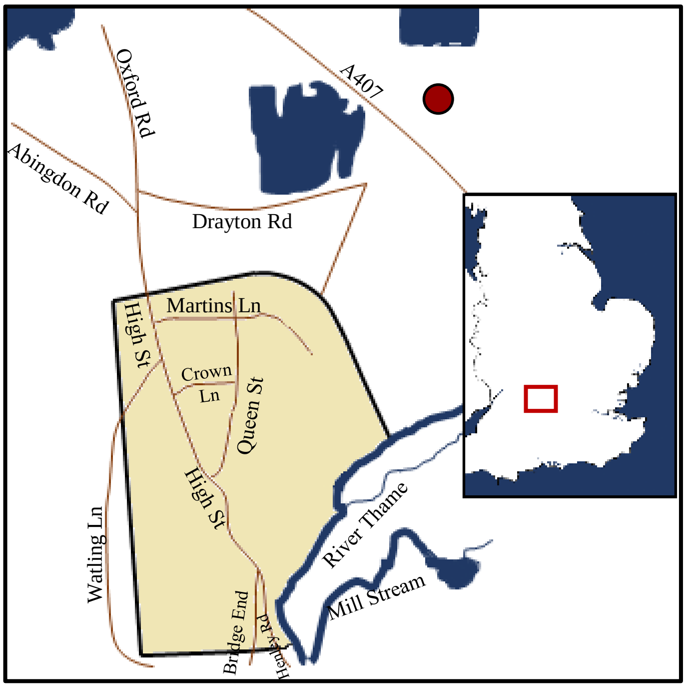


Figure 4.9: *Location of the archaeological sites of Queensford Farm and Queensford Mill, lying just outside the town of Dorchester-on-Thames. The black line represents settlement wall (after Chambers, 1987:37), with the cream colour representing the Roman town. Large blue surface is a portion of the Queensford Lakes. Source: Author.*

4.3 Early Medieval Archaeological Sites

This subsection will outline all 15 archaeological sites analysed dating from the Early Medieval period (Fig. 4.10). The sites have been grouped here into crude geographical regions, as some had only a few individuals to statistically compare with regard to stress indicators, stature, and body proportions. Sites were divided based on proximity to one another, with one exception; the site of Apple Down in Chichester was analysed separately from the other southern sites within the Hampshire region (Alton, Droxford, Portway, Shavard's Farm, Winnall, and Worth Park). All six of these sites fall within 15 miles of Winchester, whereas the site of Apple Down is almost twice that at ~30 miles away. Another reason for splitting the southern region this way is due to the large number of inhumations analysed at Apple Down. Therefore, it was deemed reasonable to separate Apple Down from the six other southern sites to distribute number of individuals between regions as evenly as possible. It must be noted that these sites were combined into these geographic regions to facilitate statistical intra- and inter-period comparisons and are not intended to reflect any regional ethnic or cultural affiliations. Sites were compared with one another in order to identify any anomalous results, prior to being amalgamated into these six regional categories (Oxfordshire, Hampshire, Eastern, Kent, Castledyke (northern), and Apple Down (southern).

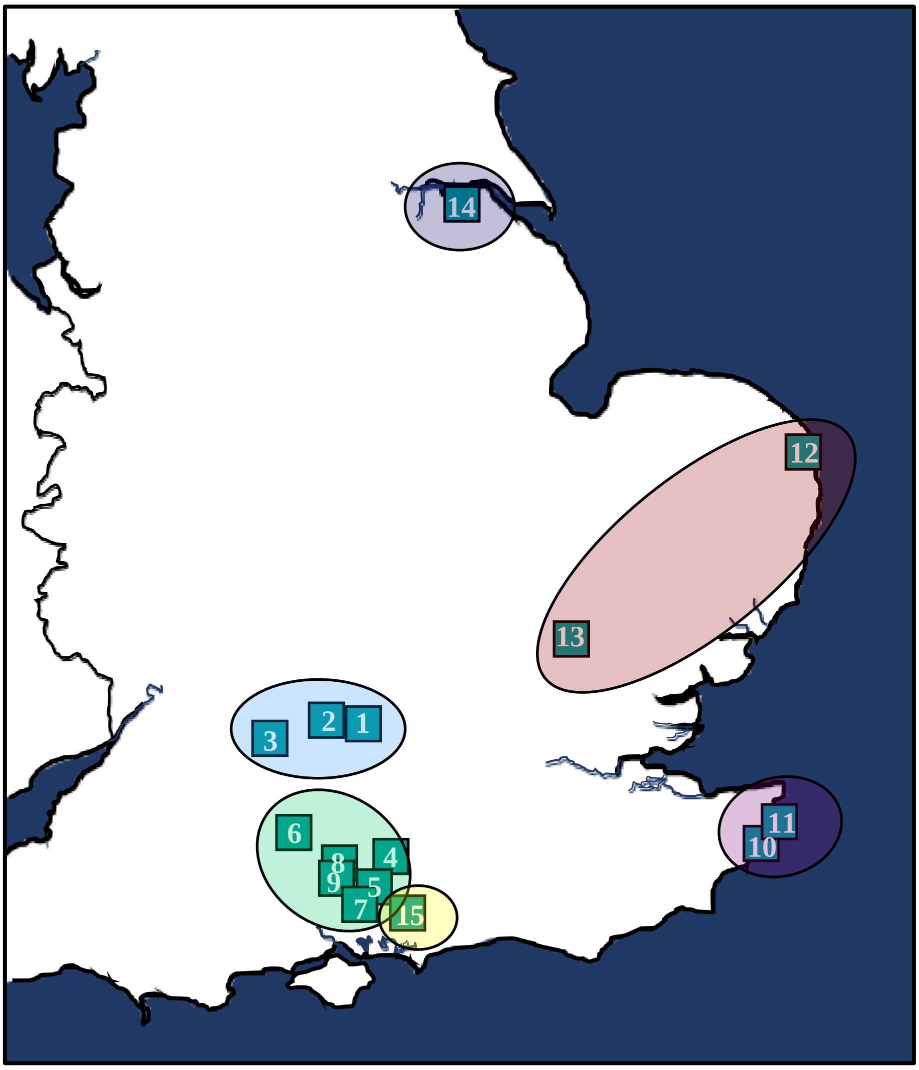


Figure 4.10: *All Early Medieval archaeological sites analysed within this thesis. 1=Berinsfield, 2=Abingdon, 3=Watchfield, 4=Alton, 5=Droxford, 6=Portway, 7=Shavards Farm, 8=Winnall, 9=Worthy Park, 10=Buckland, 11=Mill Hill, 12=Caister-on-Sea, 13=Wicken Bonhunt, 14=Castledyke, 15=Apple Down. Regions highlighted: Light Blue=Oxfordshire, Green=Hampshire, Purple=Kent, Red=Eastern, Dark Blue=Castledyke, Yellow=Apple DownSource: Author.*

4.3.1 Berinsfield, Oxfordshire

Rescue excavation at the Wally Corner gravel pit north of Dorchester in the Upper Thames Valley (Fig. 4.11) in 1974 led to the discovery of of 100 inhumations containing 114 burials with calibrated radiocarbon dates from AD 344-556 at the 95% confidence level (Hills and O'Connell, 2009:1101). A mixture of males, females, and non-adults were recovered totaling 118 individuals (31 females, 30 males). Grave goods included materials associated with weaponry (25 graves) and jewellery (24 graves). One of the brooches interred with an individual was similar to those found on the Continent, leading archaeologists to believe that this was one of the earlier Saxon settlements in this area (Boyle *et al.*, 1995:142). The grouping of inhumations may represent two or three households or farmsteads (Boyle *et al.*, 1995:143). Unfortunately, only one-half to two-thirds of the cemetery was excavated and based on the material obtained it was likely in use for a period of 150 years (Boyle *et al.*, 1995:142).

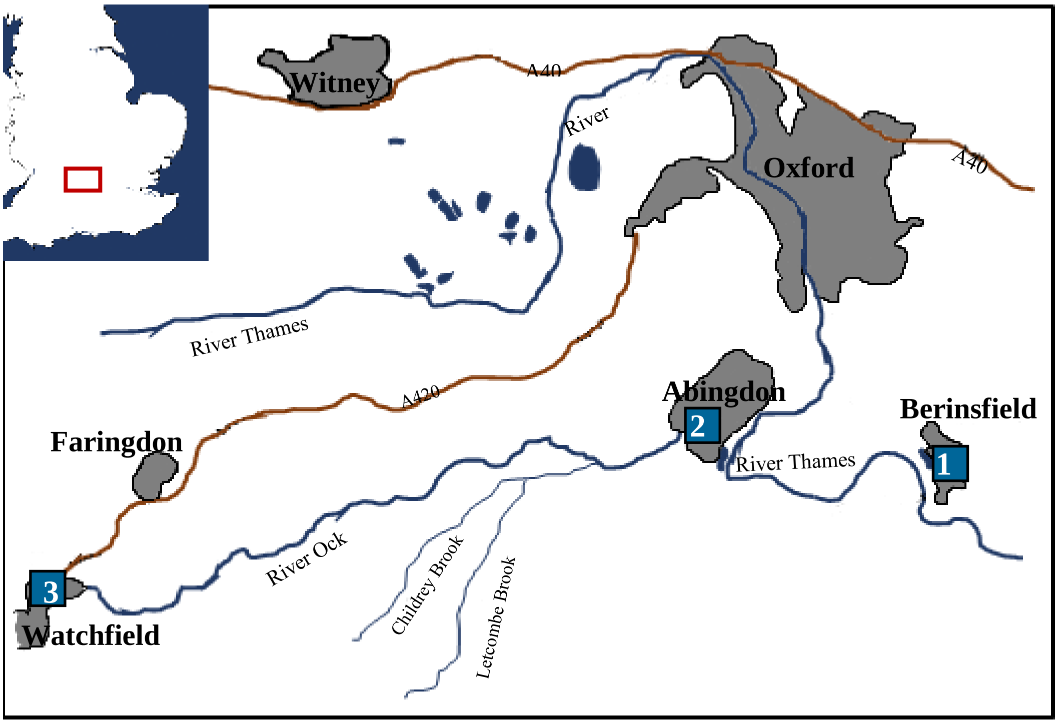


Figure 4.11: *Archaeological sites located within the Oxfordshire region. These three sites were placed into one group for the purposes of statistical analysis within the results chapter. All sites located south of Oxford. Blue line represents water (lakes, rivers, and brooks). Brown lines represent modern roadways. Black lines represent modern city lines.. 1=Berinsfield, 2=Abingdon, 3=Watchfield*

4.3.2 Abingdon, Oxfordshire

The Anglo-Saxon cemetery at Saxton Road in Abingdon, Oxfordshire (Fig. 4.11), was excavated by Lee and Harden in 1934-1935 (Leeds and Harden, 1936), with further graves discovered after the initial excavation (Leeds and Bradford, 1942:102). A total of 123 inhumations and 82 cremations were recorded with a mixture of females,

males, and non-adults included in the cemetery (Leeds and Harden, 1936). Though two burials rites were discovered, it was believed that these practices occurred simultaneously (Leeds and Harden, 1936). Lee and Harden (1936) dated the cemetery to AD 425-625, suggesting an early occupation of the Thames Valley during this period (Leeds and Bradford, 1942:103). Analysis of the sex and age estimation of skeletal remains from this site was undertaken by Rebecca Gowland for her PhD thesis (Gowland, 2002) and this information will be included here.

4.3.3 Watchfield, Oxfordshire

Twenty-six inhumations dating to the late 5th and early 6th centuries AD were discovered in 1983 during a salvage excavation by the Oxford Archaeological Unit amidst the construction of the Shrivenham by-pass near Watchfield in Oxfordshire (Fig. 4.11). Another 17 inhumations were recorded in 1988-89 in a subsequent investigation to discern more about this site (Scull, 1990). In total, 43 inhumations and two urned cremations were recovered from both excavations (CAT, 2001). Males, females, and non-adults were all included in the cemetery with both north-south and east-west grave orientations (Scull, 1990:43). Many of these individuals were interred with various grave goods dating to the 6th century AD such as shield bosses, spearheads, and knives (Scull, 1990:50).

4.3.4 Mount Pleasant, Alton, Hampshire

The construction of a new bungalow on Mount Pleasant Road at Alton, Hampshire (Fig. 4.12) uncovered human skeletal remains dating to the early Anglo-Saxon period. In total, 49 inhumations and 46 cremations were excavated, although the full extent of the cemetery was not uncovered. The majority of artefacts dated to the 5th and 6th centuries AD and it was postulated that this settlement had contact with populations inhabiting Andover and King’s Worthy (Parfitt and Brugmann, 1997:44).

4.3.5 Droxford, Hampshire

Originally identified in AD 1900, the Anglo-Saxon cemetery at Droxford (Fig. 4.12) was formally excavated in 1974, with the recovery of 41 inhumations of which

21 were identified as females and 12 as males (Aldsworth and Welch, 1979). Located close to a Bronze Age barrow, it was classified as a pagan Anglo-Saxon cemetery dating from the late 5th to 6th centuries, and likely in use for 150 years (Aldsworth and Welch, 1979:175). The majority of the inhumations were oriented in an east-west alignment with only four inhumations demonstrating a north-south alignment dating later than the previous 37 inhumations (Aldsworth and Welch, 1979:162).

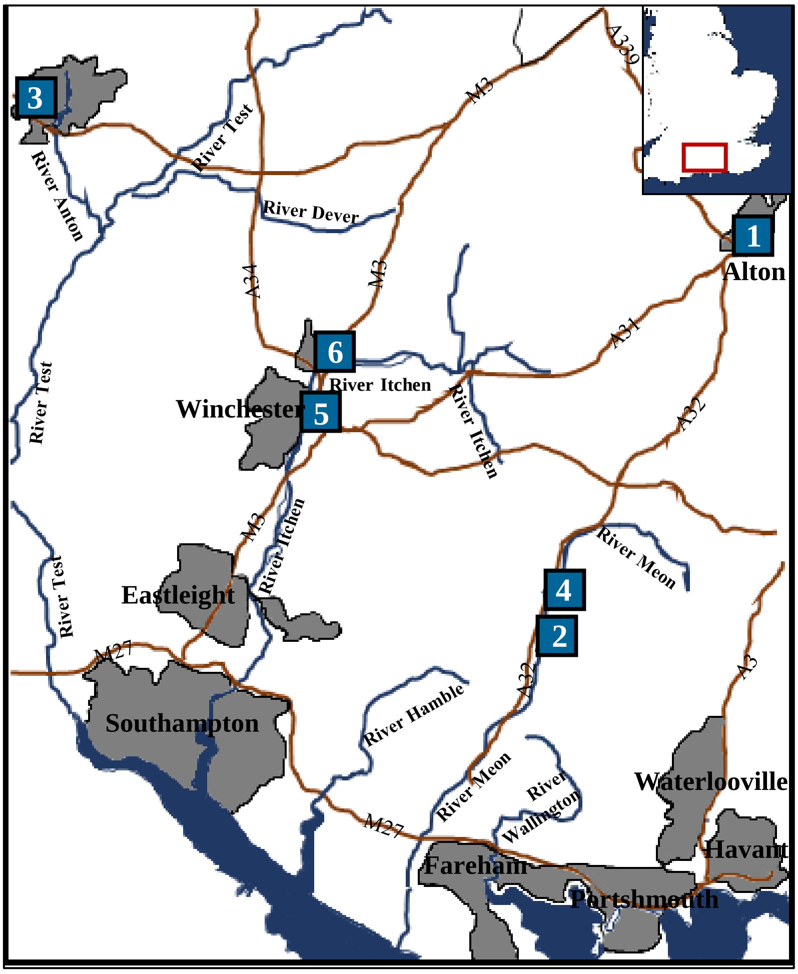


Figure 4.12: *Archaeological sites located within the Hampshire area. These six sites were grouped into the region of 'Hampshire' to enable statistical analyses to be conducted within the results chapter. Blue lines represent the major rivers flowing by each site. 1=Alton, 2=Droxford, 3=Portway, 4=Shavards Farm, 5=Winnall, 6=Worthy Park.*

4.3.6 Portway, Andover, Hampshire

The Anglo-Saxon cemetery at Portway (Fig. 4.12) was discovered during the construction of the Portway Industrial Estate between 1973 and 1975 (Cook and Dacre, 1985). Excavations revealed 69 inhumations and 87 cremations, dating from the late

5th and 6th centuries AD. It was strategically located between two Roman roads, indicating travel and communication from multiple locations throughout southern England (Cook and Dacre, 1985). Inhumations were aligned parallel (south-north) to the ditch running along the eastern boundary of the cemetery (Cook and Dacre, 1985:52). The ratio of male and female estimated human skeletal remains was 1:1.69 (Cook and Dacre, 1985).

4.3.7 Shavard's Farm, Hampshire

Various excavations throughout the 1980s occurred in the Meon River Valley, (Fig. 4.12) with the discovery of a small cemetery dating to the 6th and 7th centuries AD at Shavard's Farm, Meonstoke uncovered in 1998 and 1999 (Aldsworth and Welch, 1979:132). This site was located near Bronze Age barrows in the area on the promontory of a river terrace (Stoodley and Stedman, 2001: 130). A total of 15 burials were uncovered, revealing the remains of 21 individuals (Stoodley and Stedman, 2001:138).

4.3.8 Winnall Down, Winchester, Hampshire

Construction of a workshop near Winnall (Fig. 4.12), a village located just outside of Winchester, in 1955 uncovered human skeletal remains that were dated to the Anglo-Saxon period. The site was excavated in 1957 and 1958 (Meaney and Chadwick Hawkes, 1970), revealing 45 graves oriented in a west-east alignment, in a somewhat haphazard manner, with variations in grave size and depth (Meaney and Chadwick Hawkes, 1970:29). The earliest burials at the site were dated to the mid-7th century AD (Meaney and Chadwick Hawkes, 1970).

4.3.9 Worthy Park, Winchester, Hampshire

The Anglo-Saxon cemetery at Worthy Park just north-east of Winchester (Fig. 4.12) was discovered during the Second World War when land from the Worthy Park House was requisitioned to be used as an American military base. Construction of this base revealed human skeletal remains and a rescue excavation took place in 1944 (Chadwick Hawkes and Grainger, 2003:5). In 1961, the opportunity to undertake further excavations at this site was granted and 94 inhumations and 46 cremation burials were recovered (Chadwick Hawkes and Grainger, 2003). Only half of the entire cemetery was excavated (Chadwick Hawkes and Grainger, 2003). Many individuals were interred in the supine extended position and approximately 68 inhumations included grave goods such as pottery, copper alloy pins, iron knives, shields, or belts (Chadwick Hawkes and Grainger, 2003). Activity at the cemetery occurred for a maximum of 200 years and burials ceased in the mid-7th century AD.

4.3.10 Buckland, Dover, Kent

The Anglo-Saxon cemetery at Buckland, Dover (Fig. 4.13), was excavated in two separate phases (Parfitt and Anderson, 2012). The first excavation took place in 1951 during which 171 graves were uncovered (21 females and 19 males) dating from AD 475 to AD 750 (Evison, 1987; Parfitt and Anderson, 2012). The second excavation was carried out by Canterbury Archaeological Trust in 1994 and recovered a further 244 inhumations (Parfitt and Anderson, 2012:1). A considerable number of individual were interred with grave goods such as knives, buckles, bead necklaces, spears, swords, shield bosses, and glass and pottery vessels (Parfitt and Anderson, 2012:30-31). When both excavations were combined, a total of 415 graves were recorded, with the cemetery in use by a number of small family settlements within a larger community (Parfitt and Anderson, 2012:368).

4.3.11 Mill Hill, Deal, Kent

Rescue excavations of an Anglo-Saxon cemetery conducted by the Dover Archaeological Group ahead of the construction of a housing estate occurred between 1986 and 1989 (Parfitt and Brugmann, 1997). This revealed 132 burials, the majority of these inhumations (76 of 132) dating to the 6th century AD (Parfitt and Brugmann, 1997). The cemetery at Mill Hill (Fig. 4.13) provided a sheltered coastal environment and fertile soil (Parfitt and Brugmann, 1997:7,10). Based on the number of individuals exhumed during the excavation of this cemetery, it has been suggested that it was used by a small farming/fishing community for just over a century (Parfitt and Brugmann, 1997:10). Nineteen of the 76 graves were interred with grave goods such as spears, shields, or swords, with grave alignments mostly north-east to south-west or east-west in orientation (Parfitt and Brugmann, 1997:10).

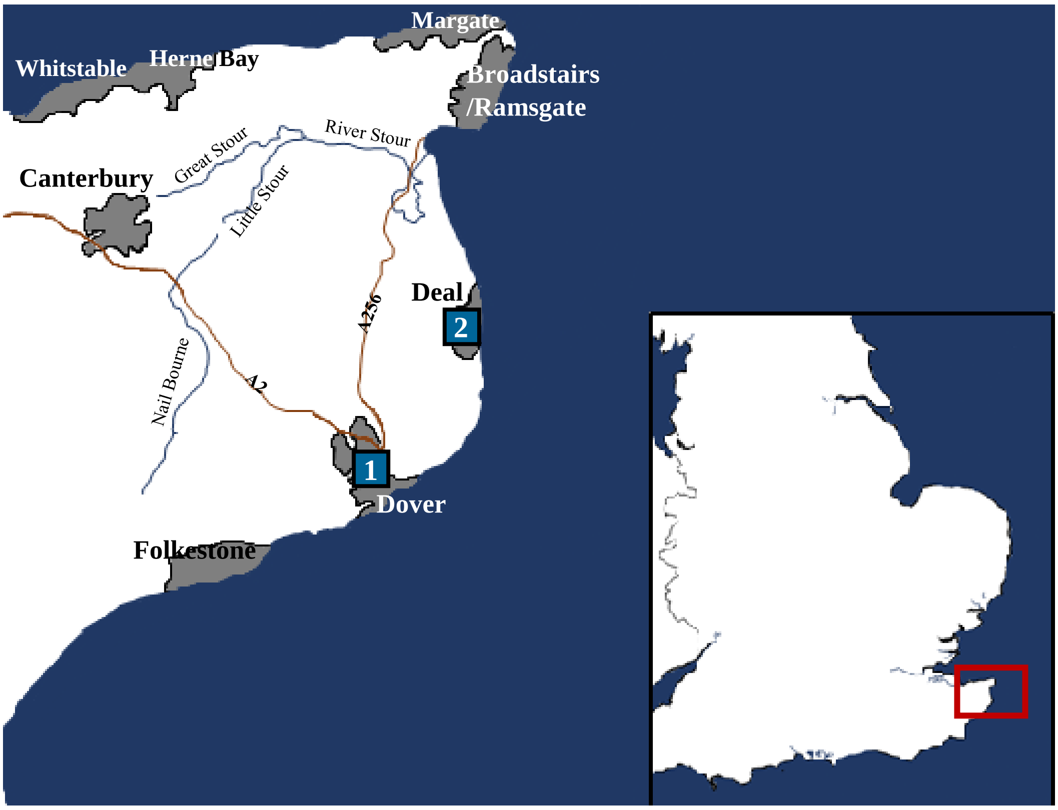


Figure 4.13: Archaeological sites located within the Kent region. Both sites are near the southeastern coast of Britain. 1=Buckland, 2=Mill Hill.

4.3.12 Caister-on-Sea, Norfolk

This cemetery (Fig 4.10), located in a remote area within the Roman walls, was excavated between 1951 and 1955. A total of 147 burials (139 individuals) dating between the 8th and 9th centuries were recorded, mostly in 1954 (Darling and Gurney, 1993:48). The burials were aligned in rows with the bodies supine and in the extended position oriented, with feet to the east and heads to the west, but without the inclusion of grave goods (Darling and Gurney, 1993). The majority of the burials date within the first two phases of the cemetery between AD 720 and 820 (Darling and Gurney, 1993:52). Interestingly, many of these inhumations were referred to as 'boat or pseudo-ship' burials by Charles Green as a number of them contained clench nails formerly used as boat fittings as well as conjoined strakes from boats as material for coffin lids, demonstrating the recycling of materials (Darling and Gurney, 1993:253-254). Only a portion of the cemetery was excavated, leading Darling and Gurney (1993) to conjecture a possibility of 3000-4000 graves at this site (Darling and Gurney, 1993: xvii).

4.3.13 Wicken Bonhunt, Saffron Walden, Essex

A local archaeologist, Bari Hooper, discovered an Anglo-Saxon cemetery within the parish of Wicken Bonhunt (Fig. 4.10) in 1967 (Wade, 1980:96), with the excavation of 49 human skeletal remains the following year (Wilson and Hurst, 1969:251). In the summers of 1971 through 1973, rescue excavation recovered a total of 222 inhumations. Approximately 19 male individuals displayed trauma, possibly indicating a battle, fight, or execution (Wade, 1980). Overall, the cemetery has been dated to mid-6th to late 7th centuries.

4.3.14 Castledyke, Barton-on-Humber, Lincolnshire

The most northerly site utilized for this thesis was Castledyke South in Barton-on-Humber, Lincolnshire (Fig. 4.10). Original disturbance of this Anglo-Saxon cemetery occurred in 1939 when five graves were discovered (Drinkall and Foreman, 1998). Systematic excavation of the site was undertaken between 1975 and 1990, though only a portion of the cemetery was examined (Drinkall and Foreman, 1998). During these excavations, 196 graves were unearthed totaling 227 individuals dating from the late 5th and 7th centuries AD (Drinkall and Foreman, 1998). These burials were either coffined or covered, and those dating to the 6th century AD were buried with grave goods, followed by a transition in the 7th century AD which signaled a change in burial clothing and artefacts (Drinkall and Foreman, 1998). Grave goods included swords, spearheads, knives, shield, brooches, beads, jewellery, and whorls (Drinkall and Foreman, 1998:246-264).

4.3.15 Apple Down, Chichester, West Sussex

Discovery of an early Anglo-Saxon cemetery by metal-detectorists in 1981 lead to the large scale excavation of the site at Apple Down within the Compton parish between 1982 and 1987 by the Chichester Excavation Committee (Down and Welch, 1990) (Fig. 4.10). Two cemeteries were uncovered, with both inhumation and cremation burials having occurred concurrently. In total, 121 inhumations and 64 definitive cremations were plotted and recovered. The inhumations varied in alignment with both west-east and south-north orientations. Many of the individuals were accompanied by grave goods ranging from beads and brooches, to knives, spearheads, and buckles. Artefactual evidence indicates that this cemetery dates from the late 5th or early 6th century until the 7th century AD (Down and Welch, 1990). This site was most likely associated with numerous small settlements founded no later than AD 500 (Down and Welch, 1990:109) and is similar to archaeological sites south of the Thames including the previously discussed site at Droxford (Down and Welch, 1990:109-110).

4.4 Chapter Summary

This chapter aimed to provide pertinent information about all of the archaeological sites analysed in this thesis, including number of inhumations recovered from each site and number of individuals examined for the purposes of this study (see Tables 4.3 and 4.4).

Table 4.3: *The total number of females and males analysed from each Romano-British site assessed.*

Location/Area	Cemetery	Site	Inhumations discovered at each site	Inhumations analysed for this thesis		
				Male	Female	Total
Roman London	The western cemetery	BAR79	20	1	0	1
		WES89	127	8	7	15
		ATL97	19	4	3	7
		GYE92	3	1	0	1
	The southern cemetery	COSE84	7	2	0	2
		GDV96	25	1	3	4
	The northern cemetery	SRP98	130	13	7	20
	The eastern cemetery	HAY86	17	3	1	4
		MSL87	223	30	20	50
		MST87	72			
		HOO88	103	7	2	9
The Roman Suburbs of Winchester	The northern cemetery	Victoria Road East	16	5	2	7
		Victoria Road West	116	27	23	50
		Hyde Street	59	10	6	16
		Andover Road	48	14	7	21
	The western cemetery	Carfax	35	3	2	5
	The eastern cemetery	Chester Road	117	25	12	37
		St Martin's Close	32	8	7	15
Butt Road			669	111	76	187
Poundbury Camp			1400	132	137	269
Queensford Farm/Mill			157	19	19	38

Table 4.4: *The number of females and males analysed at each archaeological site dating to the Early Medieval period. Sites were arbitrarily grouped into geographic regions to enable statistical analysis within and between two periods analysed for this thesis.*

Region	**Archaeological Sites**	**Inhumations discovered at each site**	**Inhumations analysed for this thesis**		
			Male	**Female**	**Total**
Oxfordshire	Berinsfield	118	20	21	41
	Abingdon, Caldecott	123	14	12	26
	Watchfield	43	8	6	14
Hampshire	Mount Pleasant, Alton	49	9	11	20
	Droxford	41	9	16	25
	Portway, Andover	69	11	16	27
	Shavard’s Farm	21	6	3	9
	Winnall Down	45	13	14	27
	Worthy Park	94	12	9	21
Kent	Buckland	415	6	12	18
	Mill Hill	76	13	9	22
Eastern	Caister-on-Sea	147	23	30	53
	Wicken Bonhunt	222	38	18	56
Northern	Castledyke	227	27	36	63
Southern	Apple Down	121	34	34	68

Chapter Five: Methods

5.1 Introduction

This chapter describes the methods used to estimate stature in the skeletal sample, including the Fully anatomical method as revised by Raxter and colleagues (2006, 2007), the statistical techniques, and skeletal indices used to assess body proportions. With regard to the anatomical method, frequently either single vertebrae or entire vertebral sections were missing or incomplete, therefore new formulae were created to estimate these. This work was inspired by that of Auerbach (2011), but a different method was devised. This chapter will also discuss the methods used to assess health stress in human skeletal remains. Finally, a brief critique concerning the use of secondary skeletal data collated from monographs and unpublished literature will be presented.

5.2 Sex and Age Estimation

The time available to undertake primary data collection was finite, therefore, the sex and age estimations reported from the original analysis of these human skeletal collections were generally utilized in order to be able to focus on the main aims of this study. Sex and age estimations from the sites analysed by Gowland (2002) (Table 5.1) were used in place of published reports as this analysis was more recent and allowed for standardization between sites. Only skeletons with fused lower limb long bones (femora and tibiae) were included. Those individuals missing these skeletal elements had to be categorized as 'adults' within the original analysis in order to be included within this study. Individuals described as 'indeterminant sex', as well as those classified as 'non-adult' or 'subadult' were not included included in this study because stature calculations are sex-specific and the revised Fully anatomical method's soft tissue correction formulae were based on adult proportions.

Prior to recording each skeleton, the sex listed in the skeletal reports were quickly reassessed. The methods used to determine sex included the morphological differences in the pelvic region (Phenice, 1969; Sutherland and Suchey, 1991) and the cranium (Acsádi and Nemeskeri, 1970; Kelley, 1979; Workshop for European Anthropologists, 1980; Meindl *et al.*, 1985b; Buikstra and Ubelaker, 1994; Walker, 2008), with more weight given to pelvic morphology. If no pelvis was present, then sex estimation methods for the cranium were employed. Age-at-death estimations were also briefly re-evaluated to ensure that individuals had been placed into the correct age categories. Methods used to determine age included the pubic symphysis (Todd, 1920; McKern and Stewart, 1957; Acsádi and Nemeskeri, 1970; Gilbert and McKern, 1973; Katz and Suchey, 1986, Suchey *et al.*, 1988; Brooks and Suchey, 1990), the auricular surface (Lovejoy *et al.*, 1985b; Buckberry and Chamberlain, 2002), sternal rib ends (Işcan *et al.*, 1984a,b, 1985), dental wear (Brothwell, 1981; Lovejoy *et al.*, 1985a), and cranial suture closure (Meindl and Lovejoy, 1985a; Buikstra and Ubelaker, 1994).

Table 5.1: *Archaeological sites for which Gowland's (2002) sex and age estimation were utilized in place of published or unpublished osteological reports*

Time Period	**Sites Analysed by Gowland (2002)**
Romano-British	Queensford Farm/Mill
	Victoria Road
Early Medieval	Abingdon
	Alton
	Berinsfield
	Portway
	Winnall II
	Worthy Park

On the few occasions that the reassessment of sex and/or age of the skeletons during data collection disagreed with that reported in the original publications, then the sex was altered.

The lack of standardization in reported age categories between sites made it difficult to place individuals into set age categories for this thesis. Due to this discrepancy, broad age categories were created (Table 5.2). It was important to analyse stature, body proportions, and skeletal stress indicators within these age categories to examine possible differences in survivorship, specifically to determine if childhood stress/growth stunting had an impact on age-specific mortality.

Table 5.2: *Age categories employed throughout this thesis.*

Age Category in Thesis	**Age Category Recorded in Reports**
<18 years	13-19 years; 17 years
18-25 years	15-21 years; 17-25 years; ‘Young Adult’
26-45 years	26-35 years; 20-35 years; 30-40 years; 36-45 years; 35-49 years; ‘Middle Adult’
46+ years	45+; 50+; ‘Old Adult’;
ADULT	>18 years; 25+ years; ‘Adult’

5.3 Measurements

The following sub-section will describe all measurements taken during data collection and present the method utilized to calculate measurement errors for each skeletal element.

5.3.1 Osteometry

A total of 37 measurements were taken from those individuals with intact skeletons. These measurements included the height of the cranium, 24 vertebral body heights, bilateral measurements from four long bones (humerus, radius, femur, and tibia), and the articulated calcaneus/talus. All skeletal elements were measured based on criteria outlined by Martin (1928), Buikstra and Ubelaker (1994), and newly revised measurements from Fully (1956) and Raxter *et al.* (2006, 2007). The revised measurements from Fully (1956) and Raxter *et al.* (2006, 2007) pertain to the maximum vertebral body heights and articulated calcaneus and talus. Both the physiological/bicondylar and maximum lengths of the femur were measured. Descriptions of all measurements are presented in Table 5.3.

In order to record all of these measurements, a lightweight field osteometric board constructed by Paleo-Tech (instrument accurate to the nearest 1 mm), Paleo-Tech spreading calipers (instrument accurate to the nearest 1 mm), and digital sliding calipers (instrument accurate to 0.01mm) were employed to take long bone, cranial height, and vertebral body height measurements, respectively. All measurements were recorded and entered into a master Excel spreadsheet. Calculation of the author's measurement error was undertaken to demonstrate the intra-observer error for each measurement. This shows the variability of an individual taking repeated measurements and is presented below. Inter-observer error was not calculated as part of this thesis, therefore reproducibility between researchers was not examined.

Table 5.3: *Descriptions of all skeletal measurements taken throughout data collection. *measurements utilized in the revised Fully anatomical method in calculating stature from skeletal remains.*

Skeletal Element	Skeletal Measurement	Description of Measurement	Measurement Instrument
Cranium*	Cranial Height: Basion-Bregma (Ba-Br)	Bregma (superior surface, point where sagittal and coronal suture meet); Basion (inferior surface, central point on the anterior margin of the foramen magnum)	Spreading Calipers
Vertebrae*	Maximum vertebral body height of C2-L5	Maximum height of vertebral body taken just anterior to the pedicle on the left side (right side taken if left unavailable)	Sliding Calipers
Sacrum*	Height of the first sacral vertebra (S1)	Promontory of the sacrum to the fusion line of the first sacral body	Sliding Calipers
Humerus	Maximum length (HUM)	Superior surface of the humeral head to the inferior surface of the trochlea	Osteometric Board
Radius	Maximum length (RAD)	Superior surface of the radial head to the distolateral surface of the styloid process	Osteometric Board
Femur	Bicondylar/Physiological Length (FEM_b)*	Superior surface of the femoral head to the inferior surface of	Osteometric Board

		both the lateral and medial condyles	
	Maximum length (FEM_m)	Superior surface of the femoral head to the inferior surface of the medial condyle	Osteometric Board
Tibia*	Maximum length (TIB)	Without the intercondylar eminence, measure from the superior surface of the lateral condyle to the inferior surface of the medial malleolus	Osteometric Board
Calcaneus/Talus	Articulated height (TAL/CAL)*	Articulate the talus with the calcaneus, hold the lateral aspect of the inferior talus and superior calcaneus with the thumb, whilst the middle (3rd) finger is placed under the sustentaculum tali and the index (2nd) finger to stabilize both bones; measure from both the medial and lateral superior surfaces on the osteometric board to the inferior surface of the calcaneus	Osteometric Board

5.3.2 Measurement error

Unfortunately, the amount of time spent with each collection did not allow for repeat measurements of the majority of the individuals analysed, therefore the technical error of measurement (TEM) was calculated from ten complete human skeletal remains from two skeletal collections (Coach Lane and Hereford) located within the Department of Archaeology at Durham University. Table 5.4 presents the absolute technical error measurement presented in millimetres (TEM), the relative technical error measurement presented as a percentage, and the coefficient of reliability (*r*). To calculate the technical error of measurement (TEM), formulae and explanations provided in White *et al.* (2012), Ulijaszek and Kerr (1999) and Perini *et al.* (2005) were followed. The formula to determine the intra-observer error is as follows:

$$\mathrm{TEM} = \sqrt{\frac{\Sigma \mathrm{D}^2}{2\mathrm{N}}}$$

where D is the difference between measurements taken and N is the number of individuals measured. Larger mean values are associated with high TEM values and lower mean values are associated with lower TEM values (Ulijaszek and Kerr, 1999). To calculate %TEM, the following equation is used (Ulijaszek and Kerr, 1999):

$$\%\mathrm{TEM} = \frac{\mathrm{TEM}}{\mathrm{MEAN}} \text{ x } 100$$

One can also use the coefficient of reliability (*R*) which is the following equation:

$$\mathrm{R} = 1 - \left(\frac{(\text{total TEM})^2}{\mathrm{SD}^2}\right)$$

This equation shows how much of the variation in the measurements is due to factors other than measurement error.

Cranial height, femoral lengths, tibial lengths, and the articulated calcaneus/talus TEMs are smaller than the precision of the measuring device (1 mm). The relative TEM demonstrates that there is an acceptable variability in the accuracy of measurements of these skeletal elements (most being less than 2%). The coefficient of reliability demonstrates at least 88% of variability in measurements was not caused by measurement error. The measurement with the lowest measurement error was L5

(0.15 mm), whilst the measurement with the highest was femoral length (0.99 mm). It was useful to know the technical error of measurements when calculating missing vertebral body heights (Section 6.5.1) and to assess whether statistically significant differences seen between categories were "biologically meaningful" (Auerbach, 2007: 173).

Table 5.4: *The TEM, %TEM, and coefficient of reliability for each skeletal measurement taken within this thesis.*

Measurement	**Measurement Error (TEM) (mm)**	**Relative TEM (%)**	**Coefficient of Reliability (*r*)**
Cranial Height	0.22	0.17	0.99
C2	0.17	0.29	0.99
C3	0.23	1.80	0.92
C4	0.26	1.95	0.97
C5	0.26	2.04	0.94
C6	0.27	1.24	0.95
C7	0.17	1.17	0.98
T1	0.23	1.40	0.96
T2	0.19	1.04	0.98
T3	0.20	1.07	0.97
T4	0.32	1.71	0.88
T5	0.16	0.88	0.99
T6	0.30	1.59	0.94
T7	0.38	1.98	0.89
T8	0.18	0.90	0.98
T9	0.22	1.04	0.99
T10	0.20	0.91	0.99
T11	0.17	0.73	0.99
T12	0.28	1.15	0.97
L1	0.28	1.07	0.97
L2	0.22	0.81	0.99
L3	0.31	1.11	0.98
L4	0.15	0.51	0.99
L5	0.46	1.62	0.97
S1	0.48	1.48	0.97
FEM	0.96	0.22	0.99
TIB	0.47	0.13	0.99
TAL/CAL	0.99	1.39	0.93

5.4 Stature Calculations and the Revised Fully Method

The skeletal collections utilized in this study demonstrated various states of preservation and completeness. Using the revised Fully anatomical method (Raxter *et al.*, 2006, 2007) to calculate living stature requires measurements of all skeletal elements constituting stature (cranial height, all vertebral body heights, bicondylar femur length, tibial length, and articulated height of the calcaneus/talus). Although their soft tissue correction was calculated on a different sample population than the one presented here, Raxter and colleagues (2006) found "no evidence for any sex- or ancestry-related effects on the accuracy of stature prediction using Fully's technique. This is reassuring, since it implies that the technique should be equally applicable to a variety of skeletal individuals or samples" (pg. 380). This method has also been used by several other researchers to estimate stature from populations varying both temporally and geographically (see Raxter *et al.*, 2008; Vercellotti *et al.*, 2009; Auerbach and Ruff, 2010; Sládek *et al.*, 2015; Mays, 2016). Though sample size from each period was quite large, the number of individuals with all of these skeletal elements was small. The skeletal element most frequently missing was cranial height followed by individual or whole sections of vertebrae. Attempts were therefore made to estimate the heights of missing vertebrae.

5.4.1 Calculating missing vertebral elements

The necessity of estimating missing vertebral elements has been noted in other publications (Sciulli *et al.*, 1990; Allison, 2002; Little and Rubin, 2002; Auerbach, 2011). Various methods for estimating missing skeletal elements include using mean values as a 'stand-in' for specific elements (Rhode and Arriaza, 2006), using means of superior and inferior vertebral body heights for missing vertebrae, and mathematical equations using known values specific to the population sample (Auerbach, 2011). In this thesis, particular attention was given to estimating missing individual vertebral body heights and vertebral sections.

Methods of estimating both have been proposed by Sciulli *et al.* (1990) and Auerbach (2011). Sciulli *et al.* (1990) suggests averaging the maximum heights of the superior and inferior vertebral bodies of the missing vertebra. Auerbach (2011) discovered, however, that this method did not accurately estimate 'exceptional' vertebrae (C2, C3, C6, T2, T11, L1, and L5) which are a product of the curvature of the spine. For this thesis, sex specific multiple regression formulae were created for each of the aforementioned vertebrae utilizing two or three vertebral body heights (see Auerbach, 2011:74 Table 4). A new method for estimating individual vertebrae was also created specifically for this thesis. This method involved using a 'k coefficient' calculated from 112 intact vertebral columns (47 females and 65 males) from the Romano-British population and 60 intact vertebral columns (28 females and 32 males) from the Early Medieval population. Individuals with extra vertebra or any fusion of vertebral bodies were removed from the sample. The formula used to calculate the 'k coefficient' for each vertebra (C3 through L4) was:

$$k_v = \frac{x_m}{\frac{1}{2}(x_s + x_i)}$$

Where x_s is the superior vertebral body height, x_i is the inferior vertebral body height, x_k is the vertebral body height of the vertebra being estimated, and k_v is the 'k coefficient' for a singular vertebra. For example, to estimate k_v for C3, the known vertebral body height measurement of C3 (x_m), the vertebra body height of C2 (x_s) and C4 (x_i) were entered into the above formula. Coefficients for C3 were calculated for all 112 Romano-British and 60 Early Medieval individuals and then averaged to arrive at the 'k coefficient' for the vertebra. Each vertebra will have its own averaged 'k coefficient' ($\overline{k_v}$) to be used in the formula below. The 'k coefficient' is used in the following formula (a linear regression) to estimate final vertebral body height of a missing vertebra:

$$x_e = \overline{k_v} \times \left(\frac{x_s + x_i}{2}\right)$$

Using the latter method a total of 42 individuals (14 females and 28 males) were added with complete vertebral columns from the Romano-British sample and 27 individuals (13 females and 14 males) were added to the Early Medieval period sample.

The previous method can only estimate individual vertebral body heights if the superior and inferior vertebrae are present. Over half of the sample from both periods were missing entire vertebral regions (cervical, thoracic, and/or lumbar), similar to the findings in Auerbach (2011). Once again, to increase the number of individuals accessible for calculating stature using the anatomical method, missing cervical regions as well as missing cervical and thoracic regions were estimated using Auerbach's (2011) regression formulae in his publication (see Appendix 3 Table 5). The accuracy of the formulae proposed by Auerbach (2011) to estimate vertebral regions and total vertebral column length were statistically compared to 114 (47 females and 67 males) and 64 (30 females and 34 males) complete vertebral columns from Romano-British and Early Medieval individuals, respectively. Two Romano-British and four Early Medieval individuals were added to the complete vertebral column sample as these individuals displayed fusion of one or more vertebrae within the same vertebral region, thus not affecting the total length of each vertebral section. Using a *t*-test to compare the vertebral region and total column length totals from Auerbach's (2011) formulae with measurements found statistically significant differences. These differences are highlighted and discussed further in section 6.4.1.2 of Chapter 6.

Since statistically significant differences occurred between the calculated vertebral regions and total vertebral column lengths and the measured complete vertebral columns using Auerbach (2011), population specific regression equations were created using the known vertebra region and total vertebral columns lengths of 114 Romano-British and 64 Early Medieval individuals. Statistically significant differences between the lengths and vertebral regions of females and males were revealed using *t*-tests, therefore sex specific equations were created. Regression formulae using ordinary least squares (OLS) were created to estimate the length of the cervical vertebral section and total column length using the summed length of the thoracic and lumbar vertebra regions, as well as estimating the sum of the cervical and thoracic vertebral sections and total column length from the length of the lumbar vertebral region only. These regression formulae can be found in Table 6.27, Chapter Six. Standard error of the estimators (SEE) for each formula was calculated using the equation in Excel 2010:

$$\sqrt{\frac{\sum_{i=1}^{n} \hat{\varepsilon}_i^2}{\mathrm{n}-2}}$$

The percent standard error of the estimate (%SEE) was calculated by dividing the SEE by the mean length of the region being estimated. Comparisons between calculated vertebral regions and total vertebral column length and known lengths were made using *t*-tests and no statistically significant differences were discovered, therefore these population specific equations were utilized in place of Auerbach's (2011) formulae. A total of 328 (154 females and 174 males) and 141 (64 females and 77 males) individuals within the Romano-British and Early Medieval populations, respectively, have complete spinal column lengths. Using the two methods just outlined, a total of 214 Romano-British and 77 Early Medieval individuals were added to the original 114 Romano-British and 64 Early Medieval individuals with measured vertebral columns. All statistics and regression formulae were calculated using Excel 2010 and PAST (PAleontological STatistics, Version 3.14).

5.4.2 Calculating stature

The following sections describe the methods used to estimate stature of the Romano-British and Early Medieval populations using both stature reconstruction methods.

5.4.2.1 Anatomical method

The calculation of living stature using the anatomical method provides more accurate estimations of stature, because it is not affected by differences in body proportions and can also be used to calculate population specific regression formulae (mathematical method) using skeletal elements most frequently recovered intact from archaeological sites. Measurements required for the Fully anatomical method of reconstructing living stature include cranial height (Ba-Br), maximum vertebral body heights of C2-L5, length of the first sacral vertebra, the physiological/bicondylar length of the femur, tibial length, and finally the articulated height of the calcaneus/talus. Individuals without cranial, sacral, femoral, tibial, or calcaneus/talus measurements were removed from the sample. Those who displayed pathologies that could potentially impact stature, such as residual rickets or trauma, were also removed from the sample.

Prior to calculating living stature using the revised Fully anatomical method from Raxter *et al.* (2006, 2007), skeletal height (SKH) must be calculated. The calculation of skeletal height involves the summation of all skeletal elements measured in centimetres. When an individual possessed both the left and right skeletal elements, the average measurement was utilized. The calculated SKH is used in the soft tissue correction formulae produced by Raxter *et al.* (2006, 2007) to estimate the Fully anatomical stature. Whilst some publications report ‘skeletal height’ (e.g. Sciulli and Hetland, 2007), this thesis will report ‘living stature’, despite inherent errors associated with soft tissue corrections (see Section 3.2.2.1, Chapter Three). This is because a greater number of publications use ‘living stature’ to create population specific regression formulae (e.g. Vercellotti *et al.*, 2009; Auerbach and Ruff, 2010; Sládek *et al.*, 2015; Mays, 2016). The use of ‘living stature’ also allows for the comparison of past stature to data from modern popluations (Auerbach and Ruff, 2010:197).

In 2006, Raxter *et al.* published revised Fully (1956) soft tissue corrections as it was discovered that the original soft tissue correction published by Fully (1956) underestimated stature by an average of 2 cm (Raxter *et al.*, 2006:381-382). The new soft tissue correction is as follows:

$$living\ stature = 0.996 \times SKH + 11.7$$

Along with the non-age adjusted soft tissue correction formula to calculate stature using skeletal height, an age adjusted soft tissue correction was also provided as stature does decrease with age, particularly in the spinal column (intervertebral discs) (Raxter *et al*, 2006). The age adjusted soft tissue correction formula is:

$$living\ stature = 1.009 \times SKH - 0.0426 \times average\ age\ + 12.1$$

The use of broad age ranges in bioarchaeology makes it difficult to apply the age corrected soft tissue correction, however average ages from broad age categories will provide greater accuracy than using the non-age corrected soft tissue correction formula (Raxter *et al.*, 2007). Due to compression of the intervertebral discs throughout the ageing process (Friedlaender *et al*, 1977), the age corrected living stature formula was utilised for individuals within the 18-25 year and 26-45 year age categories. Therefore, the mean ages used in the age corrected soft tissue formulae were 21.5 years (for those aged 18-25 years) and 35.5 years (for those aged 26-45 years). The age adjusted formulae were not utilized for individuals without age ranges (<18 years, 46+ years, and ADULT). The age adjusted formula was not used with these categories as the non-age corrected formula was created using a population where the mean age was 54 years, thus was deemed appropriate rather than assign an upper age limit to the 46+ age category and using a mean that may not represent the individuals within this category. Variables such as sex, age, population, and geographic locations were statistically analysed for significant differences in living stature within and between periods. Statistical tests utilized to detect differences within and between these variables are discussed in section 5.8 of this chapter.

5.4.2.2 Mathematical method

From the 76 Romano-British and 23 Early Medieval individuals for whom the anatomical method could be calculated, regression formulae using the physiological/bicondylar femoral length, maximum femoral length, tibial length, sum of the maximum femoral length and tibial length, maximum humeral length, and finally maximum radial length for both females and males were created in PAST 3.14 using ordinary least squares. Similar methods used in calculating SEE and %SEE for missing vertebral sections were employed to calculate these for each regression formula. Along with SEE and %SEE, standard deviation, average differences between anatomical stature and mathematically calculated stature, margin of error, and upper and lower 95% confidence intervals were calculated in Excel 2010 and can be found in Chapter Six. Finally, mean percent prediction errors were calculated for each population and sex specific formula for each of the skeletal elements using the equation provided by Vercellotti *et al.* (2009):

$$PPE = \frac{regression - anatomical}{anatomical} \times 100$$

Stature calculated from frequently cited mathematical regression formulae were statistically compared to the 'known' stature of both populations. To determine if these equations accurately estimated stature of Romano-British and Early Medieval populations, paired *t*-tests or Wilcoxon tests were conducted in PAST 3.14. The mathematical regression formulae include Trotter and Gleser (1952, 1958), Trotter (1970), Pearson (1899), Vercellotti *et al.* (2009), Olivier *et al.* (1978), Dupertuis and Hadden (1951), Breitinger (1937), Ross and Konigsberg (2002), Bach (1965), Hauser *et al*. (2005), Černy and Komenda (1982), and Allbrook (1961). Only formulae using the maximum femur, tibia, or summed femur and tibia were statistically compared to the anatomical stature. Mean percent prediction errors using the above method were calculated for these equations to determine which was most accurate. All individuals not used in the revised Fully anatomical method had their stature calculated with these new formulae to increase the number of individuals in the total sample. Stature estimation between females and males, age categories, and geographic locations within and between samples were compared statistically.

5.5 Body Proportion Indices

The calculation of various indices provides information on morphological differences within and between sample populations. The indices calculated here included skeletal elements of the post-cranium only. Relationships between various body proportions were explored using brachial, crural, intermembral, humerofemoral, and brachiocrural indices along with the relative lower limb length versus estimated stature, relative upper limb length compared to torso height, and relative torso height. Many of these indices are revised versions of anthropometric measurements used to assess population growth, development, and health (Auerbach, 2007). To calculate the relative torso height, the modified equation using maximum vertebral body heights from Auerbach (2007) was used as the original method in Holliday's (1995) dissertation utilizes the dorsal heights of vertebrae (Auerbach, 2007:182). Changes in the proportions of upper and lower limbs in comparison to torso height can reflect climate or subsistence (Takamura *et al.*, 1988; Auerbach, 2007). The equations for each index are found in Table 5.5. When calculating indices with left and right elements, all elements must come from the same side. The left side was preferentially chosen if an individual possessed both left and right skeletal elements. Once each index was calculated, the minimum, maximum, and mean values were recorded (Appendix 4 Tables 2-28). Outliers from each index were removed prior to assessing statistical differences between females and males, age categories, site locations, and time periods and identified as individuals greater than 1.5 times the interquartile range from the median.

Table 5.5: *All nine index equations. Rad=radius length, Hum=humerus length, Tib=tibia length, Fem_m=maximum femur length*

Index	**Equation**
Brachial	$\frac{RAD\ (mm)}{HUM\ (mm)} X\ 100$
Crural	$\frac{TIB\ (mm)}{FEMm\ (mm)} X\ 100$
Intermembral	$\frac{HUM\ (mm) + RAD\ (mm)}{TIB(mm) + FEMm\ (mm)} X\ 100$
Humerofemoral	$\frac{HUM\ (mm)}{FEMm\ (mm)} X\ 100$
Brachiocrural	$\frac{RAD\ (mm)}{TIB\ (mm)} X\ 100$
Skeletal Torso Length	$\Sigma(T1\ thru\ L5)$
Relative Lower Limb Length vs Stature	$\frac{FEMm\ (cm) + TIB\ (cm)}{Estimated\ Stature\ (cm)} X\ 100$
Relative Upper Limb Length vs Torso Height	$\frac{HUM\ (mm) + RAD\ (mm)}{(\Sigma\ T1\ thru\ L5)}$ x 100
Relative Torso Height	$\frac{\Sigma(T1\ thru\ L5)}{FEMb\ (mm)\ +\ TIB\ (mm)}$ x 100

5.6 Indicators of Stress

To assess chronic illness or adversity experienced in past populations, bioarchaeologists utilize skeletal ‘stress markers’. These skeletal indicators of stress include: porotic hyperostosis or cribra orbitalia, dental enamel defects, periosteal new bone formation on skeletal elements, and stature. A body responds to stress usually caused by external factors such as poor environment, diet, or other external pressures (Goodman *et al.*, 1988; Reitsema and McIlvaine, 2014:181). These indicators are known as ‘non-specific indicators of stress’, due to their multiple and overlapping aetologies. Stress is a combination of adaptation to the environment and an interplay between biology and cultural buffering (Goodman *et al.*, 1988; Temple and Goodman, 2014). Many of these skeletal indicators represent childhood episodes of stress and these are relavant to a study of temporal trends in body proportions and stature as they may have impacted growth. Not only can an individual’s response to stress impact their overall health, but it can also potentially impact future generations (see Section 2.3.1.3 in Chapter Two) as evidenced by Rodney and Mulligan’s (2014) study of mothers and infants from war torn Democratic Republic of Congo.

Bioarchaeologists must also consider the osteological paradox (Wood *et al.*, 1992). Though our understanding of certain skeletal stress indicators remains a matter of debate, it is beneficial to record a number of these indicators when attempting to infer health from past populations. This subsection outlines the four skeletal indicator of stress examined in this thesis and the methodology used in the recording of these pathologies.

5.6.1 Cribra orbitalia

Cribra orbitalia is one of the most commonly reported lesions within the palaeopathological literature (Walker *et al.*, 2009:109). It is believed to be caused by anaemia (reduction of hemoglobin in red blood cells) or inflammation (subperiosteal reactions) (Stuart-Macadam, 1991:101; Ortner, 2003; Wapler *et al.*, 2004; Walker *et al.*, 2009:110). Lesions develop through the thinning of cortical bone along with the expansion of the internal structure of the bone (diplöe) (Fig. 5.1) (Stuart-Macadam, 1991). This expansion is caused by the over production of red blood cells within the marrow (Britton *et al.*, 1960; Moseley, 1974; Ponec and Resnick, 1984; Walker *et al.*, 2009:109). When in balance, the rate of red blood cell production equals the rate of red blood cell destruction (Walker *et al.*, 2009). Nutrients needed to maintain this balance include amino acids, iron, vitamins A, B12, B6, and folic acid (Martini and Ober, 2001). These types of lesions were originally believed to be an indicator of iron deficiency anaemia due to the important role of iron in hemoglobin production; however, some researchers now argue that cribra orbitalia is more likely to be an indicator of megaloblastic or hemolytic anaemia as the latter two produce the massive hypertrophy needed to expand the marrow (Walker *et al.*, 2009).

Figure 5.1: *Right orbit displaying the expansion of diploë known as cribra orbitalia. Photograph taken by author.*

Megaloblastic anaemia is the deficiency or malabsorption of B_{12} or folic acid (B_9) (Walker *et al.*, 2009), whereas hemolytic anaemia is the premature destruction of red blood cells (Antony, 1995).Walker and colleagues' (2009) highly influential study was, however, questioned by Oxenham and Cavill (2010) who stated that iron-deficiency anaemia must still be included as a differential diagnosis (pg. 200). Deficiency in iron and B_{12} can come from a lack of animal protein within the diet and environments with poor sanitation (gastrointestinal parasites) (Walker *et al.*, 2009; McIlvaine, 2015:997). Cribra orbitalia is an indicator of childhood deficiencies and not deficiencies occurring during adulthood (Stuart-Macadam, 1985). These lesions only form during childhood development (Lewis, 2007:97) as the main centres for red blood cell production occur in the cranial vault and medullary canals of long bones (Hoffbrand and Lewis, 1981). During this analysis, criteria provided by Stuart-Macadam (1991) were utilized to assess the presence or absence of cribra orbitalia. True prevalence rates (per orbit, not per individual) were recorded for cribra orbitalia.

5.6.2 Residual rickets

Vitamin D functions to maintain calcium homeostasis (Holick, 2006) and is essential for the proper mineralization of the bone matrix (Pitt, 1988:2090). Inadequate levels of vitamin D lead to the malabsorption of calcium and phosphorus in the body (Brickely *et al.*, 2005; Brickley and Ives, 2008), both of which are needed to mineralize newly formed osteoids, aiding in the modelling and remodeling of bone (Francis and Selby, 1997; Brickley *et al.*, 2005). Insufficient intake of vitamin D through either sunlight or dietary resources during childhood development can lead to the development of rickets (Ortner, 2003; Brickely and Ives, 2008).

The pathological changes observed in rickets are caused by a multitude of factors, including climate/latitude, skin pigmentation, and cultural practices such as covering skin with clothing or living in urban environments (Pettifor, 2004; Brickely *et al.*, 2005; Brickely *et al.*, 2014). The main source of vitamin D in humans is exposure to ultraviolet rays from sunlight on the skin which is then metabolized by the body (Brickley *et al.*, 2005:390). Vitamin D can be supplemented through the ingestion of foods with large amounts of animal fat (Meyer, 2016), such as oily fish, egg yolk, liver, and vitamin D fortified foods (IOM, 2011; Brickley *et al.*, 2014). However, a diet with high levels of unrefined cereals will impair or prevent the absorption of calcium into the body (Pettifor, 2004; Brickley *et al.*, 2014).

The term 'residual rickets' refers to healed childhood rickets that are still visible in the adult skeleton (Brickley and Ives, 2008:91). Macroscopic changes used to diagnose residual rickets in this thesis included bowing deformities of the long bones, angulation of the femoral neck (*coxa vara*), and thickening or buttressing of the posterior aspect of the femur (after Brickley and Ives, 2008:111) (Fig. 5.2). The occurrence of rickets during childhood may have lasting consequences into adulthood (Brickley *et al.*, 2014:48). Individuals displaying possible residual rickets were not included in the calculations of stature or body proportions as the length of the affected long bone would alter both recordings.

Figure 5.2: *Antero-lateral bowing of femora associated with vitamin D deficiency. Photograph taken by author.*

5.6.3 Dental enamel hypoplasia

The dentition from human skeletal remains has the potential to provide valuable information regarding the growth and development of non-adults as well as the health of adults (Łukasik and Krenz-Niedbała, 2014:297). Dental development is predominantly under genetic control and occurs at regular intervals, beginning on the occlusal surface (Goodman and Rose, 1990:62). Disruption during the process of ameloblast secretion and the calcification of the enamel matrix reduces the thickness of enamel and is referred to as dental enamel hypoplasia (Sarnat and Schour, 1941). The appearance of dental enamel hypoplasia can provide insights into possible physiological disturbances during crown development as enamel does not remodel once calcified (Kreshover, 1940; Massler *et al.*, 1941; Sarnat and Schour, 1941) leaving permanent arrest marks on the teeth (Dobney and Goodman, 1991:81). Several studies have discovered that these slight perturbations during amelogenesis are non-specific indicators of stress (Kreshover, 1960; Goodman and Rose, 1990) including malnutrition, fever, and infection (Goodman and Rose, 1990; Hillson, 2008; Ogden, 2008).

Dental enamel hypoplasia only occurs during the formation of the dentition and is therefore restricted to childhood experiences during the first 10 years of life (Skinner and Goodman, 1992; Mays, 1998).

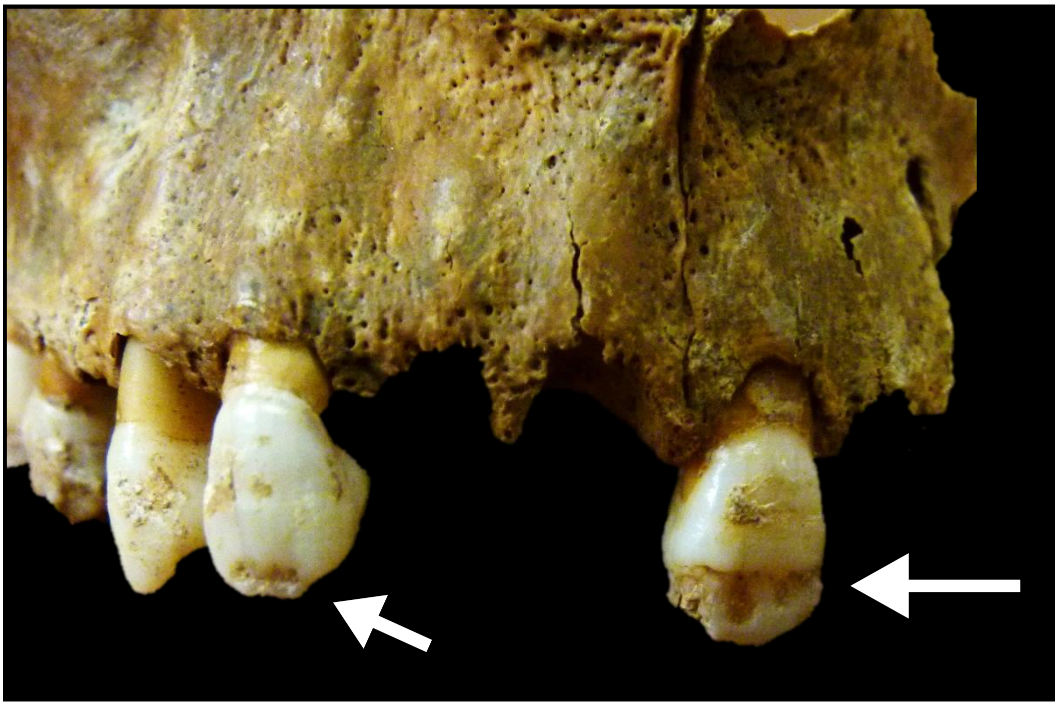


Figure 5.3: *Anterior dentition (left central incisor and right canine) demonstrating dental enamel hypoplasia. Arrows to these defects. Photograph taken by author.*

These defects can appear in the form of pits, furrows, or grooves (Fig. 5.3) (Goodman and Rose, 1990:64; Waldron, 2009:244), and usually occur circumferentially around the crown of the dentition (Hillson, 2008:303), especially when caused by metabolic stress (Goodman *et al.*, 1980, 1984a; Shawashy and Yaeger, 1986). Due to the nature of crown formation, researchers believed it was possible to estimate the age at which growth disruption occurred (Massler *et al.*, 1941; Corruccini *et al.*, 1985; Reid and Dean, 2000, 2006), however, such techniques have been critiqued (Łukasik and Krenz-Niedbała, 2014). The anterior dentition (incisors and canine) more frequently display episodes of dental enamel hypoplasia (Goodman and Armelagos, 1985a,b). Locations of the pits and/or furrows tend to occur in the central portion of the crown (Goodman and Armelagos, 1985a,b). Dental enamel hypoplasia was marked as present in an individual if two or more teeth presented dental defects such as lines, grooves, or furrows.

5.6.4 Periosteal new bone formation (periosteal lesions) on long bones

Periosteal new bone formation is the result of inflammation of the periosteum, the tissue overlaying the outer surface of cortical bone (Mays, 1998; Ortner, 2003; White *et al.*, 2012). Though inflammation is usually attributed to infectious diseases or trauma, it may be induced from various forms of irritation, stretching, or tearing of the periosteum (Richardson, 2001; Weston, 2008). The distinction between infection and inflammation needs to be addressed as inflammation is the "vascular response to tissue damage from a variety of causes", whilst infection is the introduction of foreign organisms (bacteria or virus) into the body (Weston, 2008:49). Not all inflammation of the periosteum is due to an infectious agent, though infection will often cause inflammation of the periosteum resulting in a periosteal reaction (Bush, 1989; Weston, 2012).

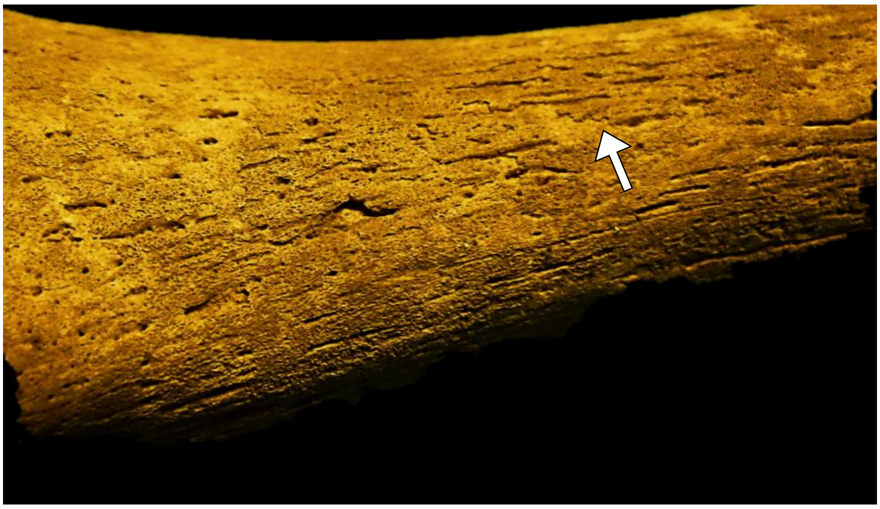


Figure 5.4: *A thin layer of woven bone over lamellar bone (arrow) on a tibia from Caister-on-Sea. Note the more 'grey' appearance of the woven bone laying on top of the cortical bone. Photograph taken by author.*

The vascular response to this inflammation promotes bone formation, therefore new bone is laid down on top of the cortical surface (Mays, 1998; Ortner, 2003; White *et al.*, 2012). New bone is originally laid down as 'woven' bone (Mays, 1998; White *et al.*, 2012), which is described as being disorganized, gray in colour, with sharp edges, when compared to cortical bone (Fig. 5.4) (Weston, 2008). Through time, this bone is remodeled into organized, smooth lamellar bone which is incorporated into the cortex (Fig. 5.5) (Mays, 1998; Ortner, 2003; Weston, 2008, 2012). These various stages demonstrate active inflammation (woven bone), healing (combination of woven and lamellar bone), and healed (lamellar bone only) lesions (Mays, 1998; Roberts and Manchester, 1997).

Figure 5.5: *Lamellar bone from a fibula that has been incorporated into the cortex. The arrow points to lamellar bone that has been incorporated in a more organized manner. Photograph taken by author.*

Focal or localized periosteal lesions indicate acute or non-systemic inflammation, whereas diffuse or prolific lesions indicate chronic or systemic inflammation (Ortner, 2003:53). This pathological lesion can be seen in conjunction with specific infectious diseases such as treponematosis or tuberculosis, as well as other infectious and non-infectious diseases (Ortner, 2003). These lesions are most often located on the shafts of long bones, particularly on the anterior surface of tibiae (Weston, 2008, 2012).

Bush (1991) noted that both physiological and psychosocial stress can impact the health of individuals and thus has the ability to leave skeletal markers of stress. However, Weston (2012) argues that a body under any amount of stress will not be capable of laying down new bone and therefore it should not be considered a stress indicator for palaeopathological analysis (pg.506). Klaus (2014) has argued that recording periosteal new bone formation provides researchers with possible differential diagnoses. During stressful periods, the body does not possess an ‘on/off’ switch with regard to the formation and destruction of bone and that there is a ‘balancing act’ between net resorption or formation (Klaus, 2014:296). DeWitte’s (2014a,b) analysis of active and healed periosteal new bone formation found that despite inconsistency in the recording of these lesions, valuable information can be provided.

Unfortunately, bioarchaeologists remain inconsistent in their recording and reporting of periosteal lesions (Weston, 2008:50). The methods used to assess periosteal lesions for this study are derived from criteria outlined in Buikstra and Ubelaker (1994). Macroscopic recording of periosteal lesions on long bones included recognizing whether the lesions were 'active' (woven), healing (combination of woven and lamellar bone), or healed (lamellar bone only). Once again, due to time constraints and limited resources, periosteal lesions were recorded as being present or absent on all long bones measured.

5.6.5 Statistical analysis for non-specific stress indicators

Presence and absence of all four stress indicators were assessed for statistical significance through Pearson's chi-square or Fisher's exact tests. Pearson's chi-square compares the frequency of variables observed against the frequency of variables expected by chance; if these variables differ then a statistically significant difference is present (Field, 2009: 688). Fisher's exact test is used when the sample size of a variable is less than five as Pearson's chi-square test provides inaccurate distributions (Field, 2009: 690).

5.7 Statistical Analyses Utilized

Outliers of the sample were removed prior to calculating statistical significance of stature and body proportions amongst sexes, ages, and geographic locations within and between periods. They were identified as values laying outside 1.5 times the interquartile range from the median. The revised Fully anatomical stature estimations for 76 Romano-British and 23 Early Medieval individuals were statistically analysed for normality using Shapiro-Wilk test, the equality of variance using Levene's test, and comparisons made using parametric and non-parametric tests. To compare differences between 'known' anatomical stature and calculated stature using regression formulae paired *t*-tests (parametric) or Wilcoxon test (non-parametric) were used to determine statistically significant differences. When assessing potential differences in stature and body proportions between groups with only two samples (females vs males, single age categories, etc) independent *t*-tests (parametric), Welch's test (non-homogenous variance), or Mann-Whitney tests (non-parametric) were calculated. Groups with multiple categories, such as age categories and geographic locations, one-way ANOVA (parametric) with Tukey post-hoc test or Kruskal-Wallis (non-parametric) with Mann-Whitney pairwise post-hoc tests were used to assess potential differences. Games-Howell post-hoc tests were used in the case of unequal variance. Data simulations using the Monte Carlo method where 9,999 permutations from each comparison were automatically created in PAST 3.14 when using the above statistical tests. The Monte Carlo permutations (MCP) are reported with exact *p*-values when possible in the next chapter.

The alpha (α) level is set at 0.05 throughout the results. However, due to the number of multiple familywise comparisons within and between the Romano-British and Early Medieval samples, it was necessary to calculate corrected alpha (α) levels to prevent Type I errors. When the level of significance is set at 0.05 (as used by many studies), this means that there is a 5 percent chance that you will find a 'false positive', a result that is considered statistically significant, but is not. This is a Type I error and to prevent this from occurring, a Bonferroni correction can be applied to adjust the alpha (level of significance) (Field, 2009). The goal for using this correction is to prevent a larger number of false positives when performing multiple comparisons (McDonald, 2009:259). To calculate the new alpha level based on the number of familywise comparisons the following equation is used:

$$corrected\ \alpha = \frac{0.05}{n}$$

where 0.05 is the current alpha level used to determine significance and *n* is the number of tests performed (McDonald, 2009:257). Caution must be used when adjusting the alpha level as if the level is too conservative, one is liable to make a Type II error or a 'false negative' (Field, 2009:373; McDonald, 2009:258). Bonferroni corrections and Tukey post-hoc tests control for Type I errors, but are also considered conservative (Field, 2009:374). The familywise comparisons were grouped into separate categories: Romano-British females, Romano-British males, Early Medieval females, and Early Medieval males. These four sex and period categorisations were chosen instead of sex or period alone to prevent Type II errors. When multiple familywise comparisons are made within the results, adjusted alpha (α) levels will be reported.

Sexual dimorphism in stature and body proportions was calculated by the following equation:

$$Sexual\ dimorphism = \frac{(m-f)}{\left(\frac{m+f}{2}\right)} \times 100$$

where 'm' was the value for males and 'f' was the value for females. Along with sexual dimorphism in body proportions, the coefficient of variation (CV) was calculated for all body proportions:

$$CV = \frac{Standard\ deviation}{mean\ value} \times 100$$

The coefficient of variation provides the amount of variation in an index whilst controlling for size. All statistics calculated for this thesis were performed in Excel 2010 and PAST 3.14.

5.8 Methodological Problems with Monographs

The archaeological sites analysed for this thesis were chosen as a consequence of 'cemetery mining' for possible sites with excavated human skeletal remains dating to the Romano-British and Early Medieval periods in Britain. Roberts and Cox (2003) provided a useful starting point, including both published and unpublished sites from these periods. Subsequently, relevant monographs, specialist reports in chapters or appendices, and articles within national, local, or county archaeological journals were examined. Sites displaying large numbers of fairly complete and well preserved human skeletal remains were highlighted and the location of the skeletons were noted. Curators at county council museums, local museums, and major museums were contacted to inquire about relevant skeletal collections housed within their museums. The museums curating the human skeletal remains analysed are listed in Table 3 within Appendix 5.

Of the 20 major sites chosen, adequate time was not always available during each museum visit to record all data in its entirety. This further limited the number of sites available for study. To limit reanalysis of the published human skeletal material, the sex and age estimations reported in specialists reports were used to determine which burials to examine, especially in collections with a sizable number material available. As Caffell (2004) has noted, many skeletal reports vary in the methods used to assess sex and age, record pathologies, condition of the skeletons, and number of skeletons recovered from the site. Few provided tables with the context codes and burials numbers along with the sex and age estimations from all skeletons. Regrettably, not all reports stated the methods utilized to assess the sex and age of the skeletal material or whether these individuals displayed any pathologies. Therefore, sex and age estimations were reviewed using methods stated above (Section 5.2).

5.9 Chapter Summary

This chapter has provided information on the methods employed within this thesis to calculate missing vertebral elements and sections, estimate stature using the revised Fully anatomical method, and the calculation of body proportions utilized within this thesis. It also introduced the four stress indicators recorded to infer possible health insults during growth and development. Benefits and concerns arising from the use of these indicators of stress were reviewed as well as the statistical analysis employed to compare frequencies between the sexes, age categories, and periods. The following chapter will report the results found.

Chapter Six: Results

6.1 Introduction

This chapter will present the results of the following analyses: the sex and age distribution of the study sample; the prevalence of four commonly assessed stress indicators (cribra orbitalia, dental enamel hypoplasia, periosteal new bone formation, and residual rickets); estimated stature using the revised Fully anatomical method; and body proportions from both the Romano-British and Early Medieval periods. The sex and age distribution of study sample (section 6.2), along with the presence of the four stress indicators (section 6.3) are compared between sexes, age categories, and within and between periods (addressing research question number 5). Due to the smaller sample sizes for those individuals displaying periosteal new bone formation and residual rickets not all statistical analyses could be computed, however the results are presented in Appendix 2. The primary focus for this study was to determine if frequently cited mathematical regression formulae used to calculate stature of both Romano-British and Early Medieval individuals accurately estimate living stature. This was accomplished by utilizing the revised Fully anatomical method as outlined in section 5.3 of Chapter Five of this thesis. New equations were created and compared to several formulae using the maximum length of the femur, length of the tibia, and summed lower limb length. These results address research questions 1, 2, 4, and 6 and are presented in section 6.4. Finally, long bone lengths and nine indices and relative body proportions were examined with results presented in section 6.5 (addressing research questions 3, 6, and 7).

6.2 Age and Sex Distribution of the Study Sample

6.2.1 Romano-British sample

From the five regions studied a total of 758 individuals dating to the Romano-British period were recorded and analysed. The number of individuals sexed as male or female is presented in Table 6.1. Individuals with indeterminate sex were not included because stature and body proportions can be sexually dimorphic (Tanner, 1962; Eveleth, 1975; Bharati, 1989; Sciulli and Hetland, 2007; Hauspie and Roelants, 2012:72).

The age-at-death distribution of this sample is presented in Figure 6.1. Over three-quarters of individuals were estimated to have been between 18 and 45 years at death. The number and percentage of males and females within each age category is presented in Figure 6.2 and Table 6.1. Overall, males aged 26-45 years were most frequently represented (29.4%). Over half of the sample were aged within the 26-45 year age category. This is a common feature of demographic profiles produced from archaeological populations and may be due to a statistical bias in skeletal age estimation techniques, which results in the under-ageing of older individuals (Bocquet-Appel and Masset, 1982; Aykroyd et al., 1997; Chamberlain, 2006). A higher percentage of females (1.8% greater) aged between 18-25 years are present than males and this is usually ascribed to 'obstetrical hazard' (Stone and Walrath, 2006).

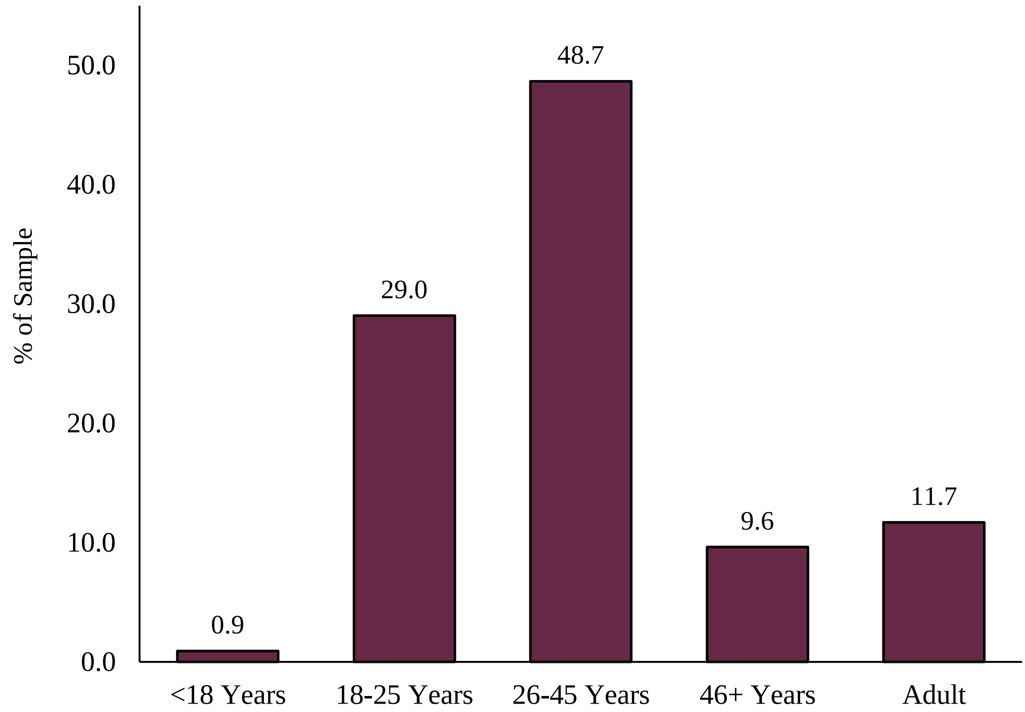


Figure 6.1: *Age-at-death distribution for the total Romano-British sample.*

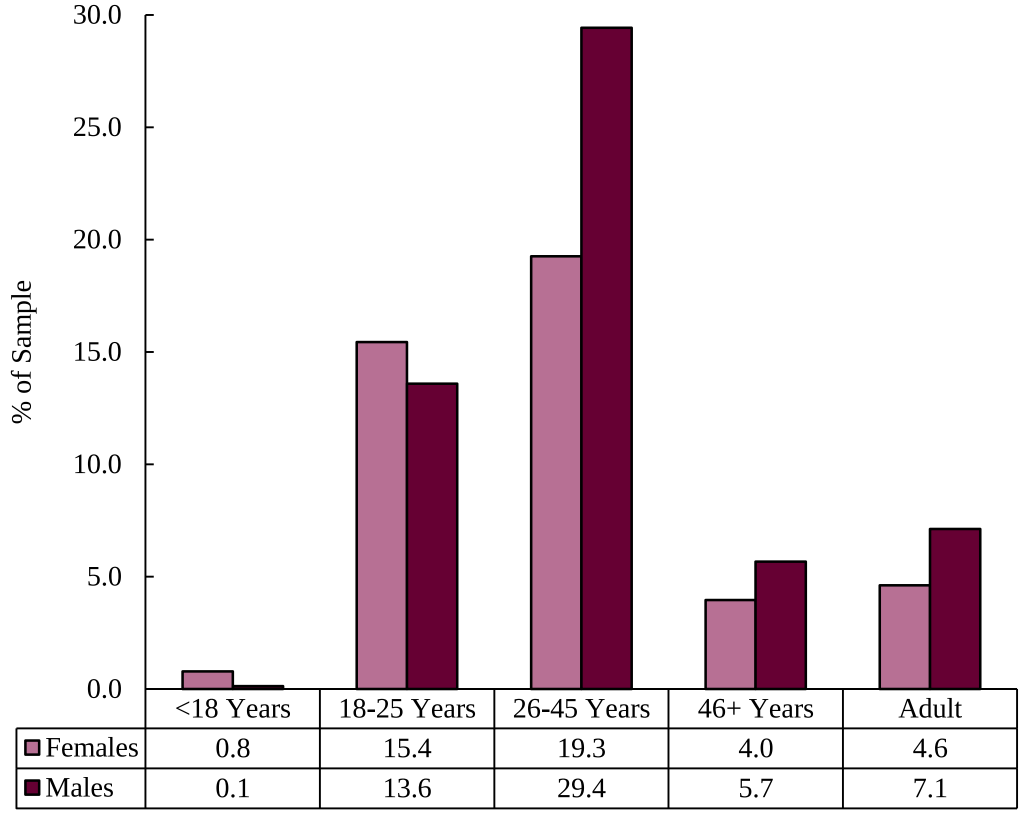
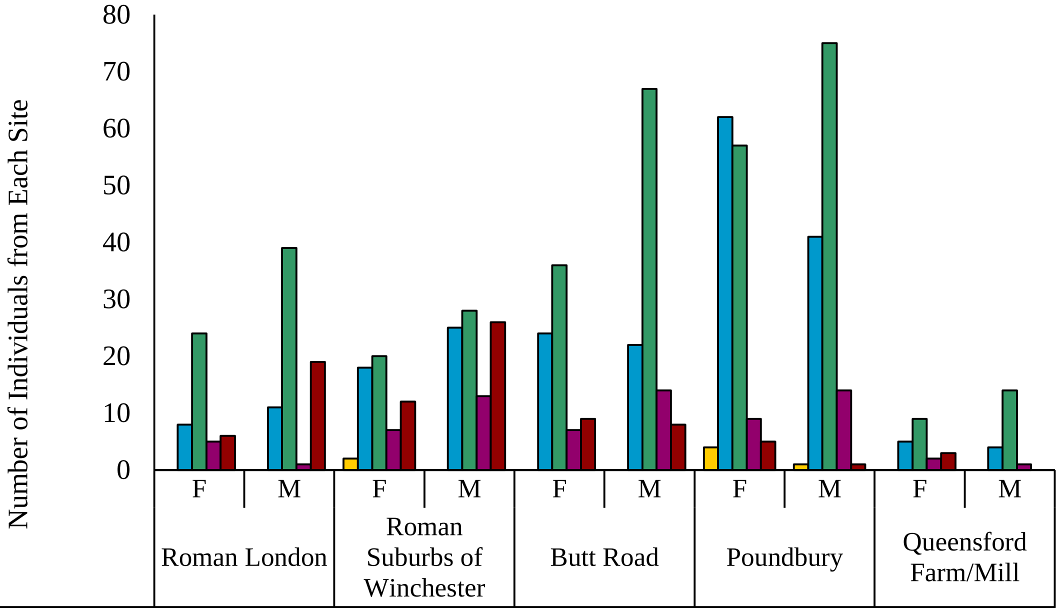


Figure 6.2: *Age-at-death distribution of Romano-British females and males. See Table 6.1 for number of individuals within each category.*

Table 6.1: *Percentage of females and males in the total sample and within each age category of the Romano-British sample. (N=number of individuals examined)*

Age Categories	**Females**			**Males**		
	N	**% Age Category**	**% Total Sample**	**N**	**% Age Category**	**% Total Sample**
<18 years of age	6	85.7	0.8	1	14.3	0.1
18-25 years of age	117	53.2	15.4	103	46.8	13.6
26-45 years of age	146	39.6	19.3	223	60.4	29.4
46+ years of age	30	41.1	4.0	43	58.9	5.7
Adult	35	39.3	4.6	54	60.7	7.1
Total	334		44.1	424		55.9

This sample was sub-divided by sites to investigate possible differences in the age and sex composition between regions. The number of males and females for each age category by site can be found in Figure 6.3. Females are not well represented in the sites of Roman London, the Roman Suburbs of Winchester (RSW), and Butt Road when compared to Poundbury and Queensford Farm/Mill (QFM) (Fig. 6.4).



	Roman London F	Roman London M	Roman Suburbs of Winchester F	Roman Suburbs of Winchester M	Butt Road F	Butt Road M	Poundbury F	Poundbury M	Queensford Farm/Mill F	Queensford Farm/Mill M
<18 Years	0	0	2	0	0	0	4	1	0	0
18-25 Years	8	11	18	25	24	22	62	41	5	4
26-45 Years	24	39	20	28	36	67	57	75	9	14
46+ Years	5	1	7	13	7	14	9	14	2	1
Adult	6	19	12	26	9	8	5	1	3	0

Figure 6.3: *Number of females and males within each age-at-death category at each Romano-British site analysed. F=female, M=male.*

It is uncommon to have an equal representation of males and females within Roman archaeological sites (Hamlin, 2007; Redfern, 2007, 2008; Pitts and Griffin, 2012; Redfern *et al.*, 2012), making the latter two sites unusual. Poundbury has been identified as an unusual Roman site within Britain due to poorer health, higher infant mortality rates, lower survivorship and higher mortality risks for adults (Redfern *et al.*, 2015:116). Sex and age-at-death distributions for each cemetery can be found in Appendix 1, Tables 2-3. This sample represents individuals that had measureable long bone elements and/or observable crania. It is not suggested that these sex and age distributions are a true representation of each cemetery, or indeed the living population from which they were derived.

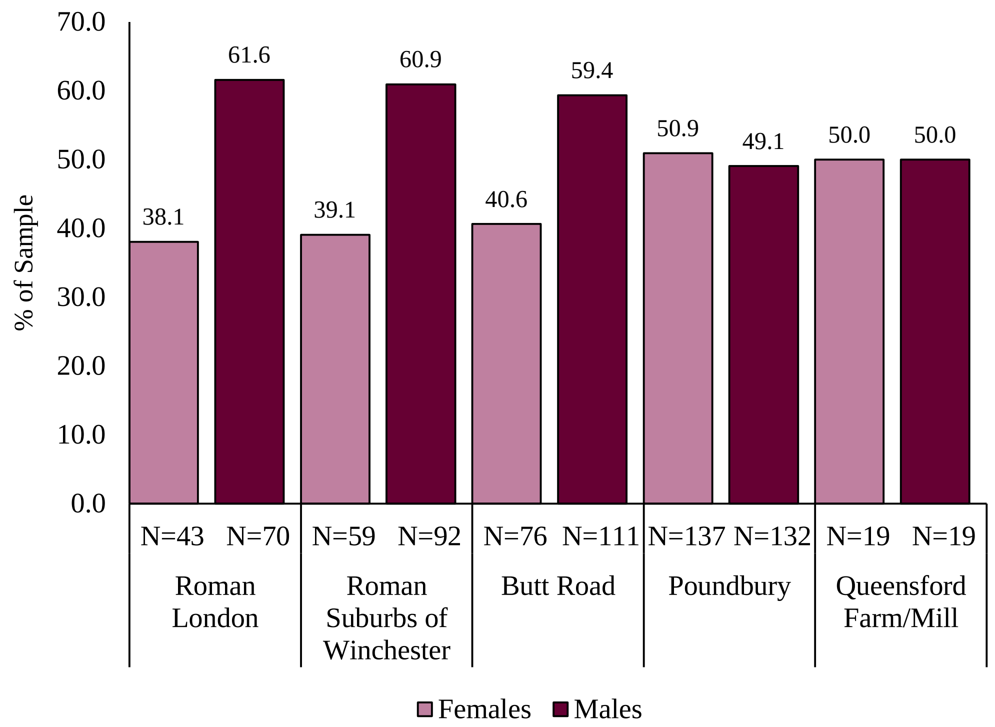


Figure 6.4: *Comparison of the sex distribution between Romano-British sites analysed. N=number of individuals in each category examined.*

6.2.2 Early Medieval sample

Fifteen cemetery sites dating to the Early Medieval period yielded a sample of 490 individuals. These sites are located throughout the central, east, south, and southeastern regions of England. The sex ratio of the Early Medieval sample was almost exactly 1:1 (Table 6.2). This ratio of males to females differs from a similar study of Early Medieval cemeteries from Cambridgeshire and Bedfordshire by Klingle (2012). Klingle’s (2012) analysis found more males to be present in cemetery populations from this area. The age distribution of the sample in this thesis can be found in Figure 6.5. Similarly to the Romano-British sample, there are more females within the 18-25 year age category than males, but also slightly greater numbers of older females than males within the sample (Table 6.2).

Table 6.2: *Number and percentage of females and males in the total sample and within each age-at-death category for the Early Medieval sample examined.*

Age Categories	Females			Males		
	N	% Age Category	% Total Sample	N	% Age Category	% Total Sample
<18 years of age	2	66.7	0.4	1	33.3	0.2
18-25 years of age	58	64.4	11.8	32	35.6	6.5
26-45 years of age	98	46.9	20.0	111	53.1	22.7
46+ years of age	73	55.3	14.9	59	44.7	12.0
Adult	16	28.6	3.3	40	71.4	8.2
Total	247		50.4	243		49.6

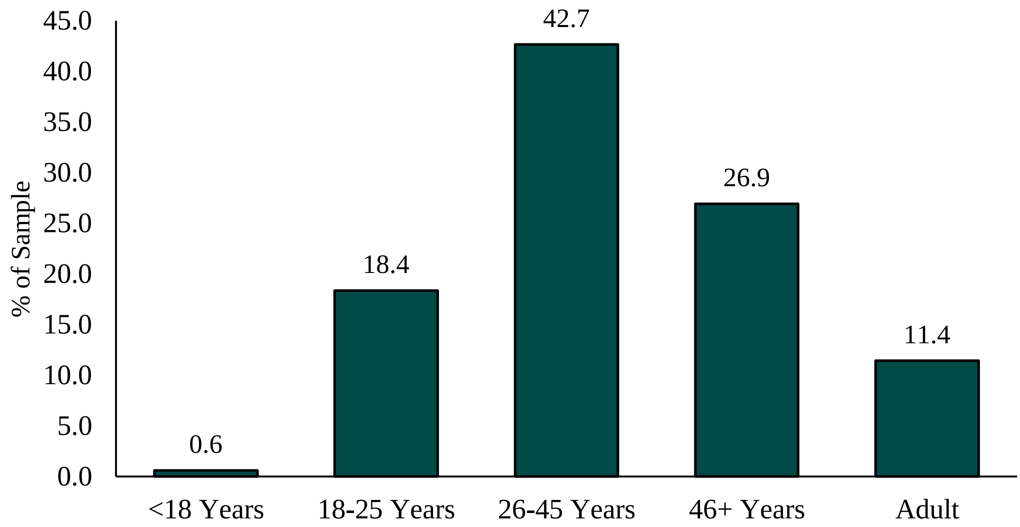


Figure 6.5: *Age-at-death distribution of total Early Medieval sample.*

This sample was further divided into the 15 archaeological sites based on sex and age-at-death. The results of this can be found in Appendix 1, Tables 4-9. One considerable difference between the various sites is the composition of females and males. Table 6.3 illustrates that more females were included from the sites of Alton, Berinsfield, Buckland, Caister-on-Sea, Castledyke, Droxford, Portway, and Winnall, whilst Abingdon, Mill Hill, Shavards Farm, Watchfield, Wicken Bonhunt, and Worthy Park had a greater number of males with suitable preservation.

Table 6.3: *Number and percentage of females and males analysed within each Early Medieval site. N=number of individuals*

Site	Females			Males			Total	
	N	% Site	%Pop	N	% Site	% Pop	N	% Pop
Abingdon	12	46.2	4.9	14	53.8	5.8	26	5.3
Berinsfield	21	51.2	8.5	20	48.8	8.2	41	8.4
Watchfield	6	42.9	2.4	8	57.1	3.3	14	2.9
Alton	11	55.0	4.5	9	45.0	3.7	20	4.1
Droxford	16	64.0	6.5	9	36.0	3.7	25	5.1
Portway	16	59.3	6.5	11	40.7	4.5	27	5.5
Shavards Farm	3	33.3	1.2	6	66.7		9	1.8
Winnal	14	51.9	5.7	13	48.1	5.4	27	5.5
Worthy Park	9	42.9	3.6	12	57.1	4.9	21	4.3
Buckland	12	66.7	4.9	6	33.3	2.5	18	3.7
Mill Hill	9	40.9	3.5	13	59.1	5.4	22	4.5
Castledyke	36	57.1	14.6	27	42.9	11.1	63	12.8
Apple Down	34	50.0	13.7	34	50.0	13.9	68	13.9
Caister-on-Sea	30	56.6	12.2	23	43.4	9.5	53	10.8
Wicken Bonhunt	18	32.1	7.3	38	67.9	15.6	56	11.4

Due to the larger number of Early Medieval archaeological sites analysed compared to the Romano-British sites, the 15 archaeological sites were arranged into six regional groups (not based on any kingdoms within Anglo-Saxon England) to simplify descriptions of the sex and age distribution of the sample from each region (see Fig. 6.6). As stated in the methods, these sites were grouped into regional categories in order to allow for statistical analysis to be undertaken with larger sample sizes. Distribution of sites within each regional group aimed for an equal number of individuals to aid in the statistical analysis, especially when comparing to the Romano-British sites. Please note that due to the greater number of individuals analysed at Apple Down, it was not included within the Hampshire region cemetery sites despite its close geographic location.

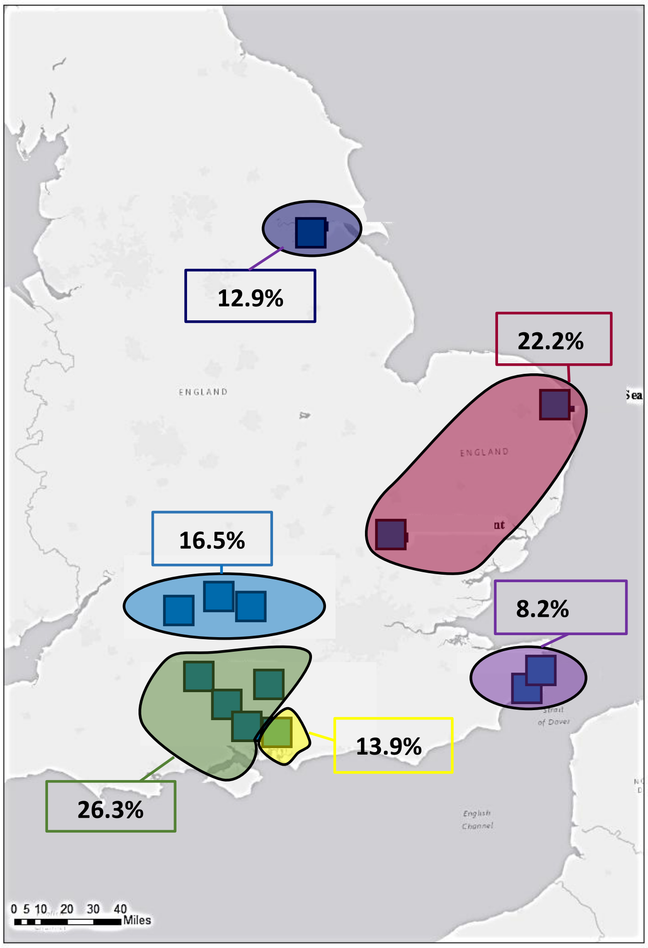


Figure 6.6: *Archaeological sites located within each assigned region and percentage of the sample each region constitutes for total Early Medieval sample analysed. Dark blue=Castledyke, Red=Eastern, Light blue=Oxfordshire, Green=Hampshire, Yellow=Apple Down, Purple=Kent.*

The percentage of females and males within each age-at-death category for each region is presented in Figure 6.7, whilst the number of females and males within each age-at-death category for each of the six regions is in Appendix 1, Table 10. A greater percentage of both females and males in the older age-at-death category of 46+ years occur at Apple Down and Castledyke (Fig. 6.7).

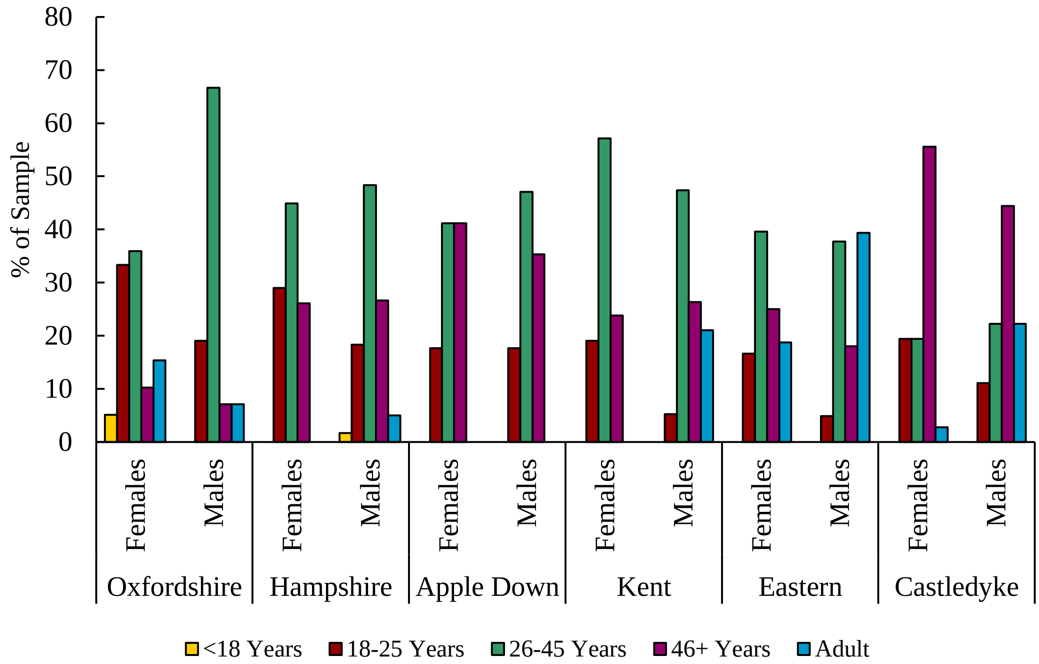


Figure 6.7: *Sex and age-at-death distribution for the six regions within the Early Medieval sample*

6.2.3 Comparison of Romano-British and Early Medieval samples

To examine possible differences in the sex and age-at-death distributions between the Romano-British and Early Medieval samples, percentages of males and females, age categories, as well as sites within similar geographic locations were compared. The sex distribution of both periods can be found in Table 6.4. More males are present in the Romano-British period, whilst the distribution of females and males within the Early Medieval period are more equal.

Table 6.4: *Number and percentage of females and males within the Romano-British and Early Medieval samples.*

Sex Estimation	**Females**		**Males**		**Total**
	N	% Pop	N	% Pop	
Romano-British	334	44.1	424	55.9	758
Early Medieval	247	50.4	243	49.6	490
Total	581	46.6	667	53.4	1248

Overall there is a greater percentage of individuals within the younger age categories in the Romano-British period, whilst the Early Medieval sample has a larger percentage of individuals in the older age categories (Fig. 6.8). When the age-at-death distributions are divided by sex estimations, this pattern between the Romano-British and Early Medieval sample remains (Fig. 6.9).

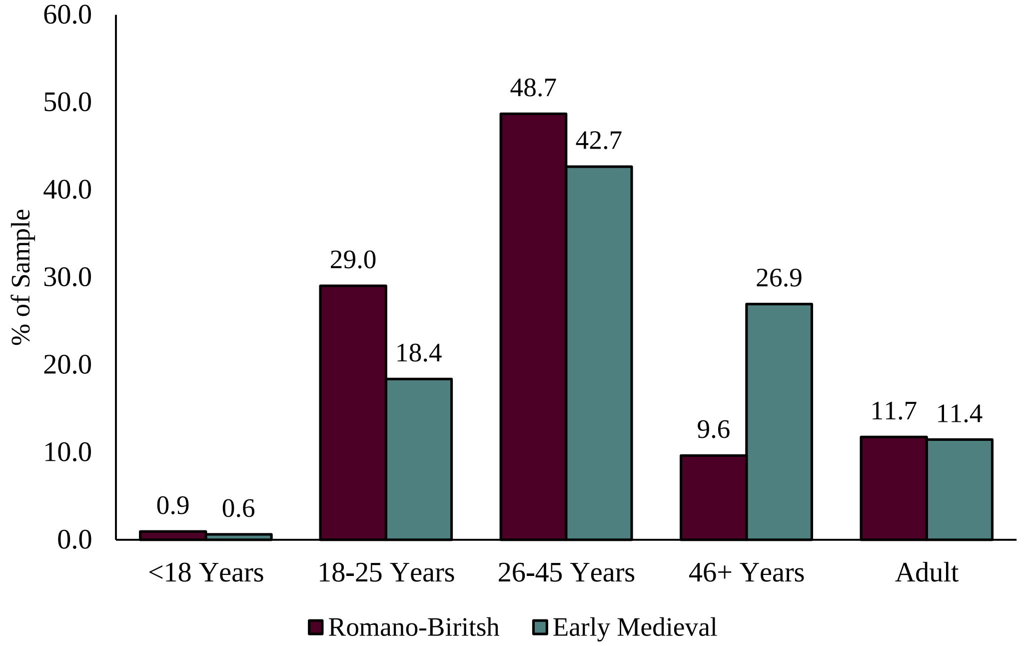


Figure 6.8: *Age-at-death distribution for both Romano-British and Early Medieval samples.*

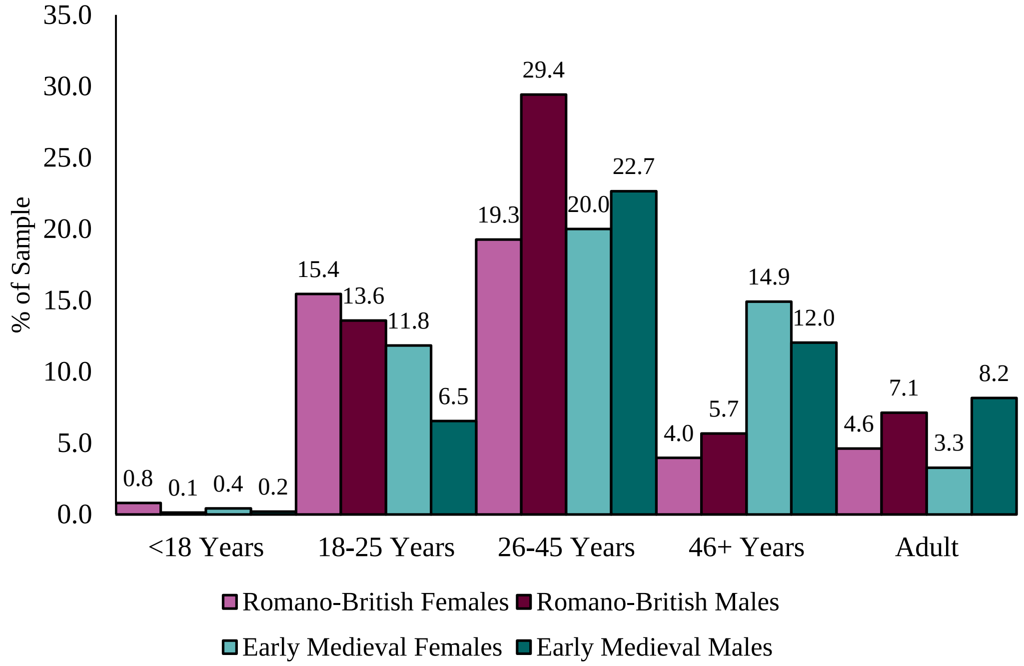


Figure 6.9: *Sex and age-at-death distribution of both Romano-British and Early Medieval samples.*

6.2.4 Summary

There was a greater prevalence of females within the younger age category of 18-25 years in both periods. A greater number of females were represented within the oldest age category (46+ years) in the Early Medieval sample and a greater number of males in the 26-45 year age category in the Romano-British sample. It should be emphasized that these data provide information on the sample composition of this study and are not presented with the aim of providing a true palaedemographic profile, because they do not represent the complete data from each cemetery.

6.3 Stress Indicators Observed During Analysis

The following section presents the results of the prevalence of stress indicators described in the previous chapter. These results will address research question 5: assessing whether there is a decrease in the prevalence of stress indicators between the Romano-British and Early Medieval periods. This is significant when examining stature, because it could relate to adversity during the growth period. The number of affected individuals and percentage of the sample demonstrating these pathologies along with chi-square (χ^2) contingency tables detecting statistically significant differences between stress indicators and a range of variables including sex, age categories, geographic locations, and periods are presented below. Only statistically significant results are presented in detail and in the interests of keeping this results chapter more digestible the remaining results are included in Appendix 2. In some instances, multiple comparisons were needed, especially within the Early Medieval sample as numerous sites were examined, therefore Bonferroni corrections were applied to adjust the alpha level (α) in order to avoid Type I errors (see section 5.7 Chapter Five). These adjusted alpha levels will be presented when utilized.

6.3.1 Romano-British Period

Every effort was made to record all relevant skeletal elements in the allotted time. This allowed the true prevalence rate of each of the skeletal indicators of stress to be assessed. However, not all skeletal elements (specifically dentition) were recorded in this manner, thus crude prevalence rates are shown for dental pathologies.

6.3.1.1 Cribra orbitalia

From the 758 individuals dating to the Romano-British period, approximately three quarters of the population had left orbits and/or right orbits preserved (Fig. 6.10).

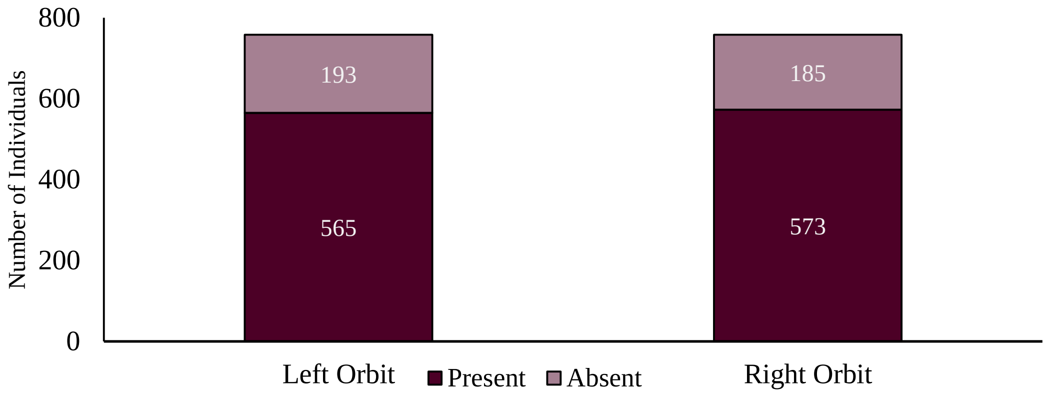


Figure 6.10: *Number of left and right orbits within the Romano-British sample analysed.*

Table 6.5 shows the number and percentage of the female and male sample with cribra orbitalia in the left and the right orbits. There was no statistically significant difference between the left and right orbits with the observation of cribra orbitalia (p=0.6348, χ^2=0.2256, df=1), therefore, the side with the greatest number of orbits present was used for analysis. There was no statistically significant difference in the presence of cribra orbitalia between females and males within the Romano-British sample (p=0.9200, χ^2=0.01, df=1).

Table 6.5: *Number and percentage of females and males demonstrating cribra ortibalia in left and right orbits that are present in the Romano-British sample analysed. CO=Cribra Orbitalia*

	Left Orbit			**Right Orbit**		
	N	Presence of CO	% Sample with CO	N	Presence of CO	% of Sample with CO
Females	247	49	19.8	252	52	20.6
Males	318	62	19.5	321	66	20.6

A greater percentage of individuals in the young adult ages presented with cribra orbitalia, with significant differences occurring in the 18-25 year and 26-45 year age categories (see Appendix 2, Table 2). These differences in age categories remain only in males when divided by sex (Appendix 2, Table 3). Finally, the presence of cribra orbitalia between sites was assessed. The percentage of individuals with cribra orbitalia in each Romano-British site can be found in Appendix 2, Table 5. When examined, statistically significant differences in the presence of cribra orbitalia between all five sites was calculated, however post-hoc pairwise testing using a Bonferroni-corrected α=0.005 failed to indicate specific pairs responsible for this difference (Appendix 2, Table 6). When assessed separately by sex, no statistically significant difference were found in the female or male samples (Appendix 2, Table 7), a greater prevalence of cribra orbitialia was observed in those under the age of 25 years, which may indicate increased frailty risk (i.e. increased risk of early mortality due to childhood stress).

6.3.1.2 Dental enamel hypoplasia

There was a higher prevalence of dental enamel hypoplasia (DEH) compared to cribra orbitalia within this sample. As stress indicators were not the key focus of this research, dental enamel hypoplasia was recorded as present or absent for each individual rather than by tooth (crude prevalence rate). Over half the individuals analysed had evidence of DEH (422 individuals). The number of females and males demonstrating dental enamel hypoplasia is presented in Table 6.6. More males displayed these defects than females, although this was not statistically significant (p=0.1100, χ^2=2.6, df=1). When examined by age categories, statistically significant differences occurred specifically between individuals in the 26-45 year and 46+ year age categories (Appendix 2, Table 11). When divided into sex-specific age categories, statistically significant differences occurred, though when the ADULT age category was removed, these differences were eliminated (Appendix 2, Tables 13 and 14 for post-hoc test results).

Table 6.6: *Presence of dental enamel hypoplasia in females and males within the Romano-British sample analysed.*

	Presence of Dental Enamel Hypoplasia	**N**	**% of Sample with Dental Enamel Hypoplasia**
Females	175	334	55.4
Males	247	424	58.3

The presence of DEH was compared between sites to assess whether any differences were present among the various geographic locations. Statistically significant differences occurred between sites and sex-specific categories, however this analysis was not the focus for research question five, therefore results have been included within Appendix 2 (see Table 16-18). In summary, despite having a greater number of males presenting DEH, the prevalence of these lesions in the male sample was only 3% greater than the female sample, indicating no statistically significant differences between the sexes.

6.3.1.3 Periosteal new bone formation on long bones

From the 758 individuals from Romano-British sites a total of 676 individuals had at least one long bone present. Only 28 individuals, or 3.7% of this sample had visible periosteal reactions on these long bones. However, many of the skeletons analysed had suffered post-mortem damage to the cortical surfaces, which would have eliminated the visible signs of periosteal new bone growth. Table 6.7 presents the number of females and males with periosteal reactions along with the number of individuals with long bones present. Statistically, this was a significant difference in the observation of periosteal reactions on long bones ($p=0.0010$, $\chi^2=10.3$, $df=1$). Unfortunately, due to the small sample of individuals presenting periosteal new bone formation (PNBF) on the long bones in each age category (see Appendix 2, Table 20), more detailed statistical assessment could not be undertaken. Between sites no statistically significant difference in the presence of PNBF was observed ($p=0.1100$, $\chi^2=7.48$, $df=4$). Individuals were divided into female and male categories and, again, no statistically significant differences were found in either category (see Appendix 2, Table 22).

Table 6.7: *Number and percentage of females and males displaying periosteal reaction on long bone within the Romano-British sample.*

	Presence of Periosteal Reaction on Long Bones	**Number of Individuals Analysed with Long Bones**	**% of Sample with Long Bones Present**
Females	4	296	1.4
Males	24	380	6.3

6.3.1.4 Possible residual rickets

The assessment of residual rickets was pertinent to this research as the torsion or bowing of long bones may affect the calculation of stature and body proportions. It has also been demonstrated in previously published material that non-adults from Poundbury tended to present higher frequencies of metabolic diseases (Lewis, 2010; Rohnbogner and Lewis, 2017). A total of 24 individuals demonstrated these pathological changes. This equated to only 3.6% of individuals with long bones present. Table 6.8 presents the number of females and males exhibiting residual rickets along with period-specific prevalence rates. Although a greater number of males demonstrated these pathological changes, no statistically significant difference between the sexes was revealed (p=0.5300, χ^2=0.40, df=1).

Table 6.8: *Number and percentage of females and males displaying bowing or torsion of long bone within the Romano-British period.*

	Presence of Residual Rickets on Long Bones	Number of Individuals Analysed with Long Bones	% of Sample with Residual Rickets on Long Bones
Females	9	296	3.3
Males	15	380	4.0

As with periosteal new bone formation, too few individuals displayed residual rickets for tests of statistical significance by age. The greatest percentage of individuals with possible residual rickets include those between 18 and 45 years of age at death (see Appendix 2, Table 23). When the presence of this pathology was assessed between all sites, a statistically significant difference occurred, though pairwise post-hoc tests were unable to detect where (see Appendix 2, Tables 25-26). Similar to the analysis of whole sites, significant differences in the presence of residual rickets were found between males from different sites with post-hoc tests unable to detect where these differences occurred (Appendix 2, Table 27). No statistically significant differences were found between sites within the female sample (p=0.2152, χ^2=5.79, df=4).

6.3.2 Early Medieval Period

Archaeological sites dating to the Early Medieval period usually contained smaller number of inhumations. Due to poor preservation and smaller cemetery sites, a total of 15 Early Medieval sites were evaluated representing a total of 490 individuals, 268 individuals less than the Romano-British sample. The following section will present the results of pathological changes (presence of cribra orbitalia, dental enamel hypoplasia, periosteal new bone formation on long bones, and possible residual rickets) by individual site, as well as the region in which each site was located.

6.3.2.1 Cribra orbitalia

From the 490 individuals evaluated, 67.6% of the total sample had the left orbit present, whilst 65.9% of the total sample had the right orbit present (Fig. 6.11). No statistically significant differences between the presence of cribra orbitalia in either orbit occurred (p=0.3700, χ^2=0.79, df=1). The number of females and males with left orbits and right orbits present along with number of each sex demonstrating cribra orbitalia are presented in Table 6.9. Both female and male samples presented a greater prevalence of cribra orbitalia in the left orbit. Similar prevalence of cribra orbitalia between females and males equates to no statistically significant difference (p=0.8700, χ^2=0.03, df=1). When cribra orbitalia was assessed by age category no statistically significant differences were found (p=0.3225, χ^2=4.65, df=4) (see Appendix 2, Table 29). Similar results were uncovered when divided into sexes (see Appendix 2, Figure 6).

The presence of cribra orbitalia was compared by site and region. Although the range in percentage of the samples presenting cribra orbitalia was large, no statistically significant difference between these 15 sites was discovered (p=0.4838, χ^2=13.66, df=14).

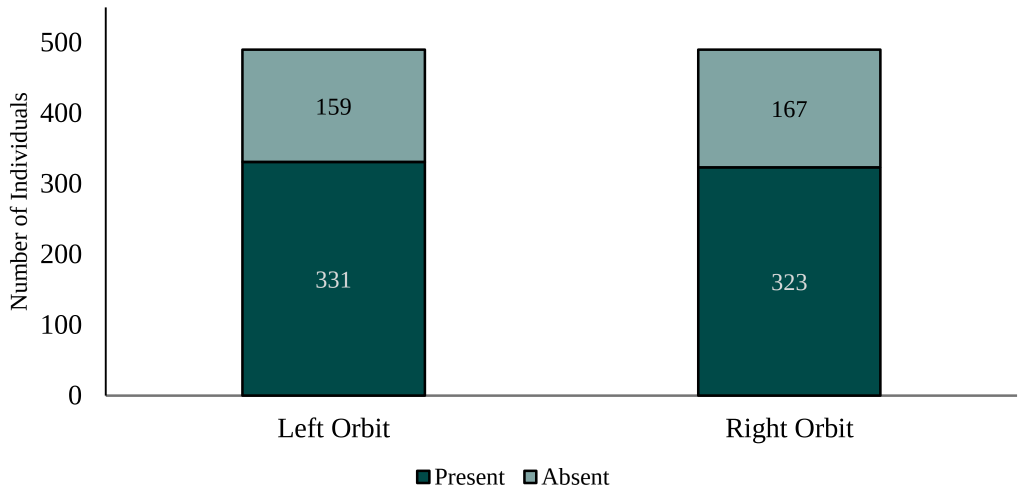


Figure 6.11: *Number of individuals within the Early Medieval sample with left and right orbits present during analysis.*

Table 6.9: *Number of females and males demonstrating cribra orbitalia in present left and right orbits within the Early Medieval sample.*

	Left Orbit			**Right Orbit**		
	N	Presence of CO	% of Sample with CO	N	Presence of CO	% of Sample with CO
Females	166	37	22.3	165	29	17.6
Males	165	38	23.0	158	35	22.2

As stated within Chapter Five, cemeteries were grouped into ‘regions’ to allow for comparisons within and between periods. The sites within each constructed region demonstrated no statistical differences in prevalence rates (Appendix 2 Table 31). When regions were compared a statistically significant difference was identified, however pairwise post-hoc tests with a Bonferroni-corrected alpha were unable to detect where this difference occurred (Appendix 2, Table 34).

Sites and regions were divided into female and male categories to assess whether differences between sexes within each site and region existed (Fig. 6.12 and 6.13, respectively). Statistically, no significant differences were uncovered between females when all 15 sites ($p=0.4731$, $\chi^2=13.87$, $df=14$) and six regions ($p=0.2414$, $\chi^2=6.87$, $df=5$) were tested. No statistically significant differences between sites within each region were found (Appendix 2 Table 35).

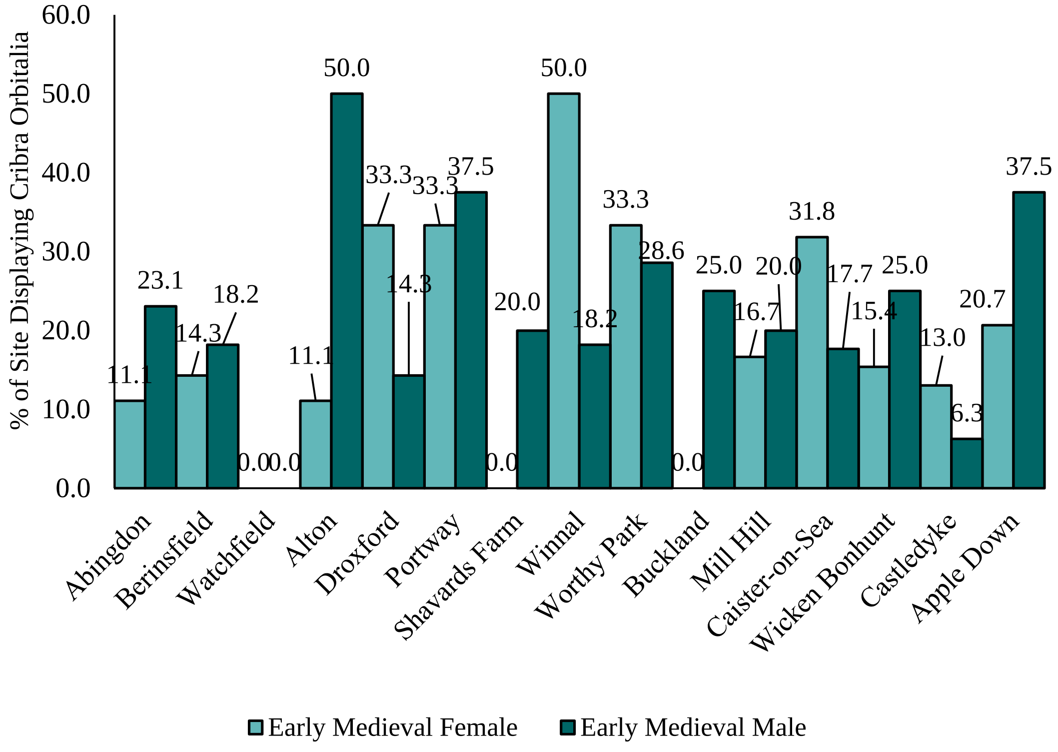


Figure 6.12: *Percentage of Early Medieval females and males displaying cribra orbitalia at each site analysed.*

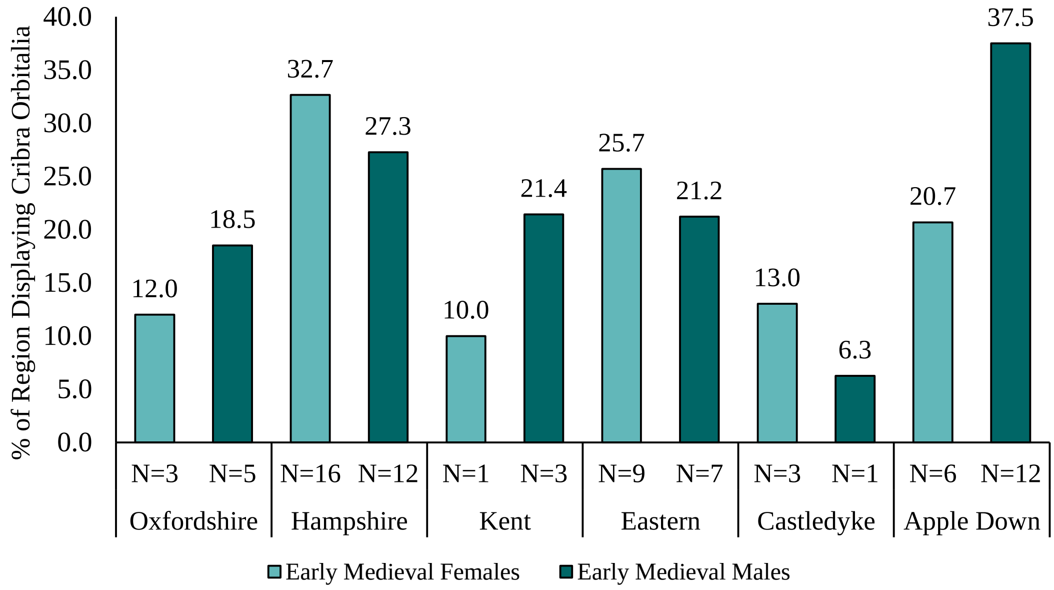


Figure 6.13: *Percentage of Early Medieval females and males demonstrating cribra orbitalia within each regional groupings of sites analysed. N=number of individuals with CO.*

Among the male sample of the Early Medieval period, no statistically significant differences between all 15 sites were uncovered despite the wide ranges in percentage of males with cribra orbitalia (p=0.6507, χ^2=11.64, df=14) or between all six regions (p=0.2395, χ^2=6.84, df=5). Similar to the female sample, the male sample presented no statistically significant differences between sites within each region (Appendix 2 Table 36). Females and males from each site and region were compared to one another to detect any differences between the sexes; no statistically significant differences between females and males emanated between sites or regions (Appendix 2 Tables 37 and 38).

6.3.2.2 Dental enamel hypoplasia

From the 490 individuals analysed from the Early Medieval period, only 171 individuals (34.9% of the total sample) demonstrated DEH. Of the total female sample (247 individuals), 83 showed clear evidence of DEH, whilst 88 of the 243 males showed these enamel defects (Table 6.10), which was not a statistically significant difference (p=0.7262, χ^2=0.18, df=1).

Table 6.10: *Number and percentage of Early Medieval females and males demonstrating dental enamel hypoplasia*

	Presence of Dental Enamel Hypoplasia	N	% of Population with Dental Enamel Hypoplasia
Females	83	247	33.6
Males	88	243	36.2

Again, the focus of research question five did not include the assessment of age categories, however they were undertaken and are presented in Appendix 2. Overall, no statistically significant differences were detected between age categories and sex-specific age categories (Appendix 2, Tables 39-42). The number and percentage of individuals with DEH at all sites and regions is presented in Tables 6.11 and 6.12, respectively. The prevalence ranged from 11.1% at Winnall to 66.1% at Caister-on-Sea. The variability in DEH between sites led to statistically significant differences overall (p<0.0001, χ^2=47.96, df=14).

Table 6.11: *Number and percentage of Early Medieval individuals displaying dental enamel hypoplasia at each site*

Site	Number of Individuals with Dental Enamel Hypoplasia	Total Site Sample	% of Site Demonstrating Dental Enamel Hypoplasia
Abingdon	9	26	34.6
Berinsfield	7	41	17.1
Watchfield	6	14	42.9
Alton	10	20	50.0
Droxford	10	25	40.0
Portway	6	27	22.2
Shavards Farm	3	9	33.3
Winnal	3	27	11.1
Worthy Park	7	21	33.3
Buckland	3	18	16.7
Mill Hill	8	22	36.4
Caister-on-Sea	35	53	66.1
Wicken Bonhunt	13	56	23.2
Castledyke	17	63	27.0
Apple Down	24	68	35.3

Table 6.12: *Number and percentage of Early Medieval individuals demonstrating DEH within sites located in various geographic regions.*

Region	Number of Individuals with Dental Enamel Hypoplasia	Total Region Sample	% of Region Demonstrating Dental Enamel Hypoplasia
Oxfordshire	22	81	27.2
Hampshire	39	129	30.2
Kent	11	40	27.5
Eastern	48	109	44.0
Castledyke	17	63	27.0
Apple Down	24	68	35.3

Pairwise post-hoc testing using a Bonferroni-corrected alpha (α=0.0004) detected significant differences between Caister-on-Sea and six different sites: Berinsfield, Portway, Winnall, Wicken Bonhunt, Castledyke, and Apple Down (see Appendix 2 Table 44) with a higher percentage of individuals presenting DEH at Caister-on-Sea driving this difference. Differences between regions was also assessed with no statistically significant differences occurring between sites within each region except

Eastern sites (see Appendix 2, Table 46). No statistically significant difference was uncovered in the total population between all six regions (p=0.0903, χ^2=9.46, df=5).

Sites and regions were further divided in to female and male categories to assess potential differences (Figures 6.14-6.15, respectively and Table 6.13). An exceptionally high percentage of females (70.0%) within the cemetery at Caister-on-Sea had evidence of DEH, whilst Buckland had the lowest. With the wide spectrum of values, a statistically significant difference between all 15 sites was uncovered (p=0.0002, χ^2=39.96, df=14).

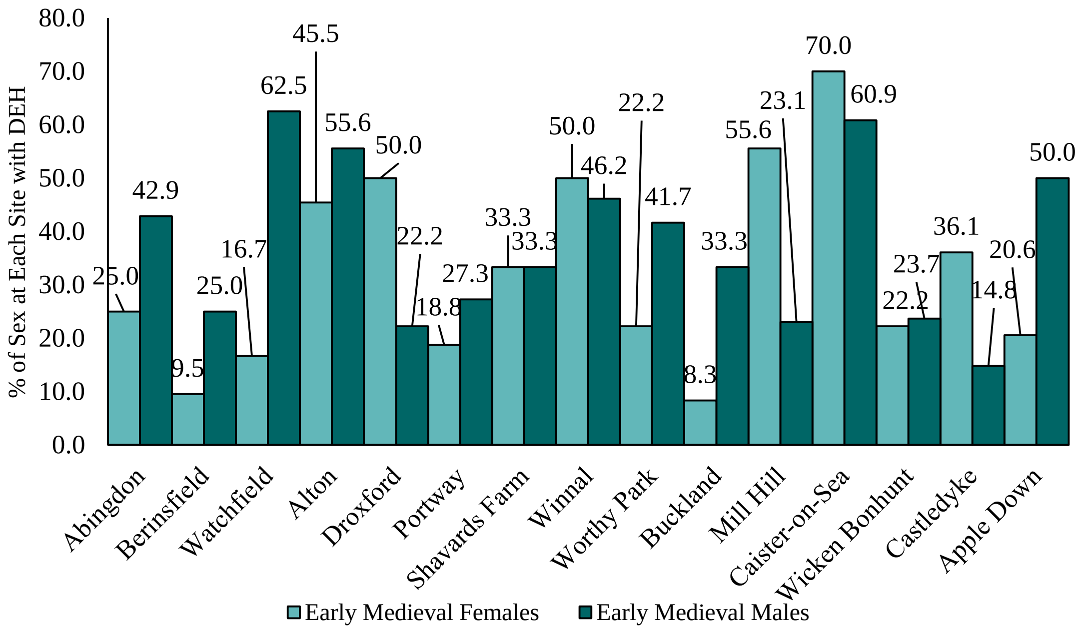


Figure 6.14: *Percentage of Early Medieval females and males within each site analysed displaying DEH.*

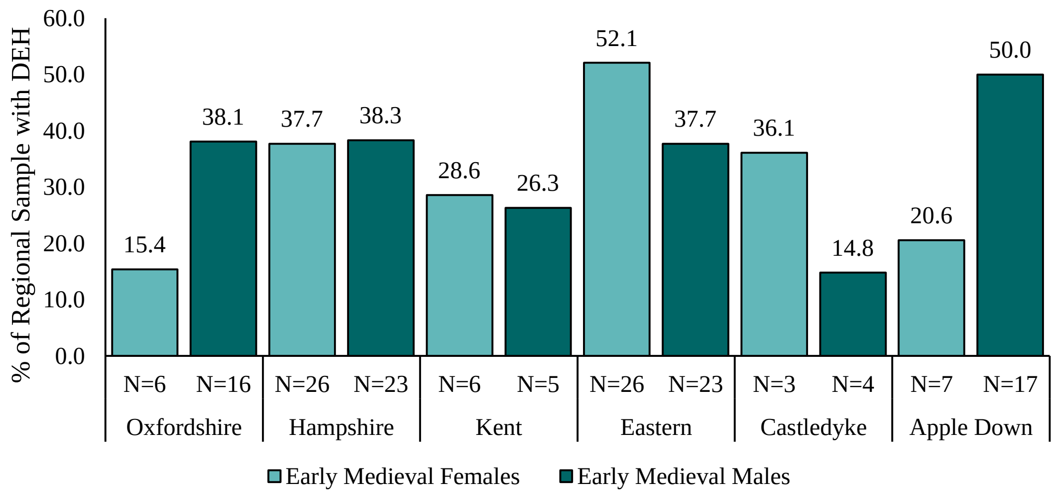


Figure 6.15: *Percentage of Early Medieval females and males displaying DEH within each region. N=number of individuals.*

Table 6.13: *Number and percentage of Early Medieval females and males presenting DEH within each site analysed.*

Site	Number of Individuals with Dental Enamel Hypoplasia		Total Site Sample Size		% of Site Demonstrating Dental Enamel Hypoplasia	
	F	M	F	M	F	M
Abingdon	3	6	12	14	25.0	42.9
Berinsfield	2	5	21	20	9.5	25.0
Watchfield	1	5	6	8	16.7	62.5
Alton	5	5	11	9	45.5	55.6
Droxford	8	2	16	9	50.0	22.2
Portway	3	3	16	11	18.8	27.3
Shavards Farm	1	2	3	6	33.3	33.3
Winnal	7	6	14	13	50.0	46.2
Worthy Park	2	5	9	12	22.2	41.7
Buckland	1	2	12	6	8.3	33.3
Mill Hill	5	3	9	13	55.6	23.1
Caister-on-Sea	21	14	30	23	70.0	60.9
Wicken Bonhunt	4	9	18	38	22.2	23.7
Castledyke	13	4	36	27	36.1	14.8
Apple Down	7	17	34	34	20.6	50.0

To determine where these differences emerged, pairwise post-hoc tests for each site was computed. For the female sample, the differences lie within Caister-on-Sea and two sites: Berinsfield and Apple Down (Appendix 2, Table 47). All females within the six regions were compared to one another and significant differences occurred ($p<0.0001$, $\chi^2 = 28.78$, df=5), specifically between Castledyke and Hampshire and Eastern regions, as well as between the Eastern region and Apple Down (see Appendix 2 Table 49). When the females were grouped into regions, no statistically significant differences emerged between the sites located within each region except for Eastern sites (Appendix 2, Table 50). Unlike the female sample, males displayed lower ranges of prevalence between sites and regions (47.69% and 35.19%, respectively). All 15 sites were compared with one another and statistically significant differences were found, however pairwise post-hoc testing was unable to determine where these differences occurred (see Appendix 2, Table 51). No significant differences were detected within the male sample when compared between the six regions (p=0.1097, χ^2 =9.20, df=5). When females and males from each site and region were compared with one another, no statistically significant differences were detected (see Appendix 2 Tables 53 and 54 for all sites and regions, respectively).

6.3.2.3 Periosteal new bone formation to long bones

Thirty out of the 384 individuals with long bones present displayed periosteal new bone formation (7.8% of the sample). Males were twice as likely to show this stress indicator than females (Table 6.14). Although two-thirds of the individuals with periosteal reaction on the long bones were male, statistically, no significant differences were detected between the two sexes (p=0.1840, χ^2=1.90, df=1).

Table 6.14: *Number and percentage of Early Medieval females and males with periosteal new bone formation on long bones.*

	Presence of Periosteal Reaction on Long Bones	**Number of Individuals Analysed with Long Bones**	**% of Sample with Periosteal New Bone Formation**
Females	10	178	5.6
Males	20	206	9.7

The number of individuals demonstrating periosteal lesions within each age category can be found in Appendix 2 as it does not directly pertain to answering research question five, although comparisons were preformed (Appendix 2, Tables 55-57). No statistically significant differences between age categories were discovered between those with periosteal new bone formation and those without (p=0.0914, χ^2=8.15, df=4). Statistically, no significant differences between age categories for females were found (p=0.2392, χ^2=5.32, df=4) and likewise for males (p=0.2052, χ^2=5.95, df=4).

The prevalence of periosteal new bone formation on long bones was investigated further to ascertain possible differences between sites and regions. The number and percentage of individuals affected within each site are presented in Table 6.15. The wide range in percentage of sample affected (from 0.0% to 38.5%) created a statistically significant difference between all 15 sites with paiwise post-hoc testing using a Bonferroni-corrected alpha discovering these differences occurred between Abingdon and individuals from both Castledyke and Apple Down (see Appendix 2, Table 59).

Table 6.15: *Number and percentage of females (F), males (M), and total (T) Early Medieval sample displaying periosteal new bone formation (PNBF) within each site.*

Site	Number of Individuals with PNBF			Number of Individuals with Long Bones			% of Sample with PNBF on Long Bones		
	F	M	T	F	M	T	F	M	T
Abingdon	4	6	10	12	14	26	33.3	42.9	38.5
Berinsfield	2	1	3	16	15	31	12.5	6.7	15.4
Watchfield	1	1	2	5	7	13	20.0	14.3	15.4
Alton	0	1	1	4	6	10	0.0	16.7	10.0
Droxford	0	1	1	5	7	12	0.0	14.3	8.3
Portway	0	0	0	2	2	4	0.0	0.0	0.0
Shavards Farm	0	0	0	3	6	9	0.0	0.0	0.0
Winnal	0	0	0	11	10	21	0.0	0.0	0.0
Worthy Park	0	1	1	3	7	10	0.0	14.3	10.0
Buckland	0	0	0	11	6	17	0.0	0.0	0.0
Mill Hill	0	1	1	8	12	20	0.0	8.3	5.0
Caister-on-Sea	2	3	5	28	23	51	7.1	13.0	9.8
Wicken Bonhunt	1	3	4	15	37	52	6.7	8.1	7.7
Castledyke	0	0	0	25	21	45	0.0	0.0	0.0
Apple Down	0	0	2	30	33	63	0.0	0.0	3.2

The number and percentage of females, males, and total sample presenting periosteal new bone formation in each region are listed in Table 6.16. When comparing periosteal new bone formation by region, statistically significant differences occurred between sites within Oxfordshire and Eastern regions ($p=0.0050$, $\chi^2=10.43$, $df=2$ for both, see Appendix 2, Table 61). When regions were compared amongst one another significant differences occurred, specifically between the Oxfordshire region and those from Castledyke and Apple Down (pairwise post-hoc tests with a Bonferroni-corrected alpha ($\alpha=0.005$) (see Appendix 2, Table 62).

Table 6.16: *Number and percentage of individuals from each site within each geographic region displaying periosteal new bone formation on long bone dating to the Early Medieval period.*

Region	Number of Individuals with PNBF			Number of Individuals with Long Bones			% of Sample with PNBF on Long Bones		
	F	M	T	F	M	T	F	M	T
Oxfordshire	7	8	15	33	36	70	21.2	22.2	21.4
Hampshire	0	3	3	28	38	66	0.0	7.9	4.6
Kent	0	1	1	19	18	37	0.0	5.6	2.7
Eastern	3	6	9	43	60	103	7.0	10.0	8.7
Castledyke	0	0	0	25	21	45	0.0	0.0	0.0
Apple Down	0	2	2	30	33	63	0.0	6.1	3.2

Sites and regions were separated into sexes to identify variation between them (Fig. 6.16 and Fig 6.17, respectively). Only five sites (Abingdon, Berinsfield, Watchfield, Caister-on-Sea, and Wicken Bonhunt) representing only two regions had females demonstrating PNBF. Due to small sample sizes, statistical analysis was not attempted for females between sites or regions.

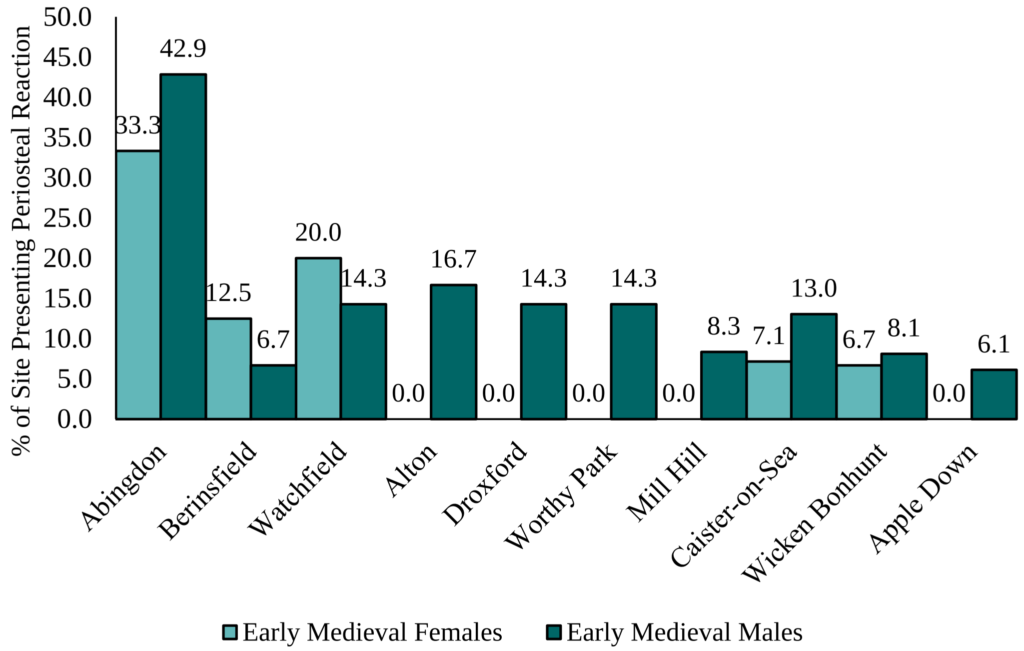


Figure 6.16: *Percentage of Early Medieval females and males within sites demonstrating periosteal new bone formation. Not all sites displayed this pathology and therefore not included. Number of females and males within each site located within Table 6.15.*

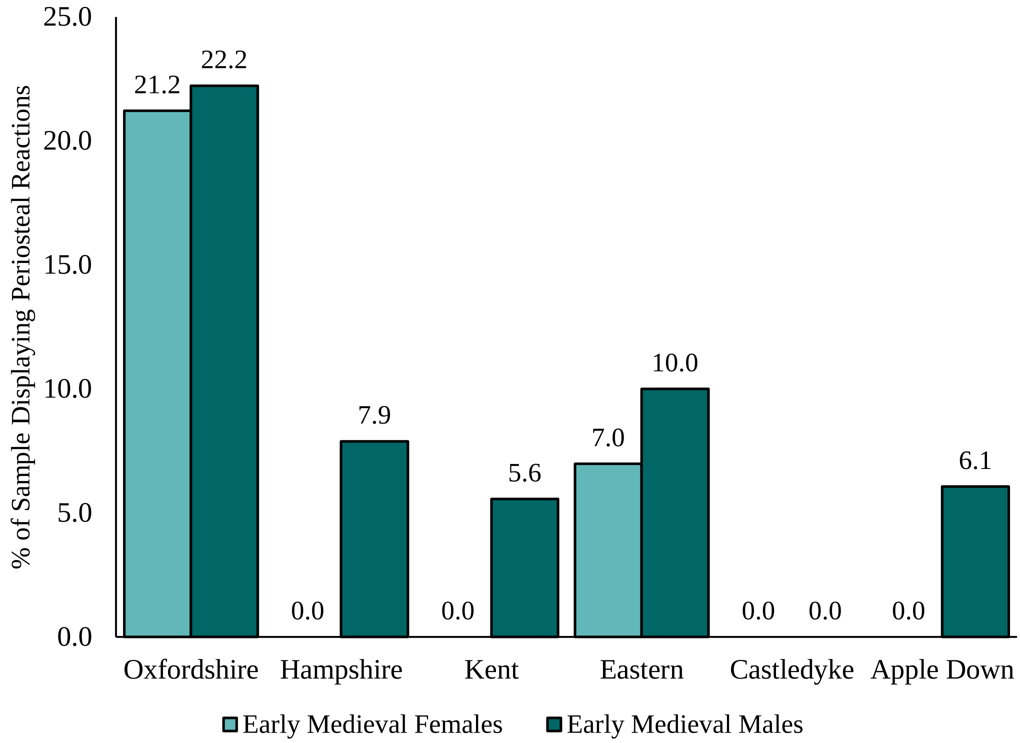


Figure 6.17: *Percentage of Early Medieval females and males from sites grouped into similar geographic regions demonstrating periosteal new bone formation. Number of individuals within each category located in Table 6.28*

Unlike the females, a greater overall number of males with periosteal new bone formation allowed for statistical comparisons between sites to be carried out. A statistically significant difference between all 15 sites in the frequency of periosteal reactions was detected (p=0.0170, χ^2=29.82, df=14) with pairwise post-hoc tests using a Bonferroni-corrected alpha (α=0.0004) identifying these differences between Abingdon and Apple Down (Appendix 2, Table 63). Five of the six regions presented males with periosteal reactions on the long bones (Fig. 6.17) with no statistically significant differences identified (p=0.0769, χ^2=9.69, df=5).

6.3.2.4 Residual rickets

A total of 13 individuals (3.4% of sample) were identified with residual rickets, with twice as many males than females affected (Table 6.17), however this did not equate to any statistically significant difference (p=0.2500, χ^2=1.31, df=1).

Table 6.17: *Number and percentage of Early Medieval females and males displaying pathological changes of the long bones associated with residual rickets.*

	Presence of Residual Rickets on Long Bones	Number of Individuals Analysed with Long Bones	% of Sample with Residual Rickets with Long Bones Present
Females	4	178	2.3
Males	9	206	4.4

Division of individuals displaying skeletal changes associated with residual rickets into the five age categories identified that 12 of the 13 individuals belonged to those in the 26-45 year age category with one in the 46+ age category (Appendix 2 Table 68). No differences between females and males within each age category (Appendix 2, Table 69) were uncovered.

When assessing geographic locations, the distribution of individuals identified as having possible residual rickets was heavily weighted towards Caister-on-Sea with six of the 13 affected individuals from this site (Table 6.18). Seven of the 13 remaining sites did not present any individuals with possible residual rickets. No statistically significant differences between all 15 sites (p=0.1624, χ^2=17.69, df=14) or regions (p=0.2794, χ^2=6.19, df=5) were identified.

Sites and regions were further divided into female and male categories to evaluate possible differences within each sample (Fig. 6.18 and Fig. 6.19, respectively). Due to the small number of individuals with residual rickets, many sites did not present any individuals with this pathology. No statistically significant differences between females and males occurred between sites or regions (see Appendix 2, Tables 72 and 73, respectively).

Table 6.18: *Number and percentage of Early Medieval individuals demonstrating possible residual rickets (RR) at each site analysed. Only sites with an individual possessing this pathology are included in this list.*

Site	Number of Individuals with Possible RR	Number of Individuals with Long Bones	% of Individuals with Possible RR
Abingdon	1	26	3.9
Watchfield	1	13	7.7
Winnal	1	21	4.8
Worthy Park	1	10	10.0
Buckland	1	17	5.9
Caister-on-Sea	6	51	11.8
Wicken Bonhunt	1	52	1.9
Castledyke	1	45	2.2

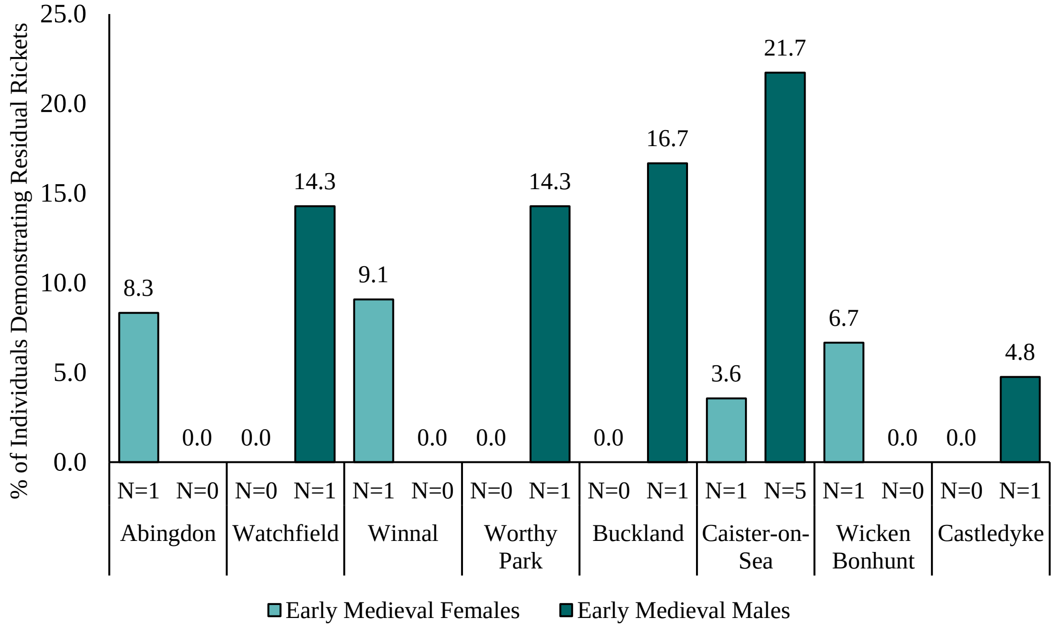


Figure 6.18: *Early Medieval sites with females and/or males displaying pathological changes on long bones associated with residual rickets. N=number of individuals.*

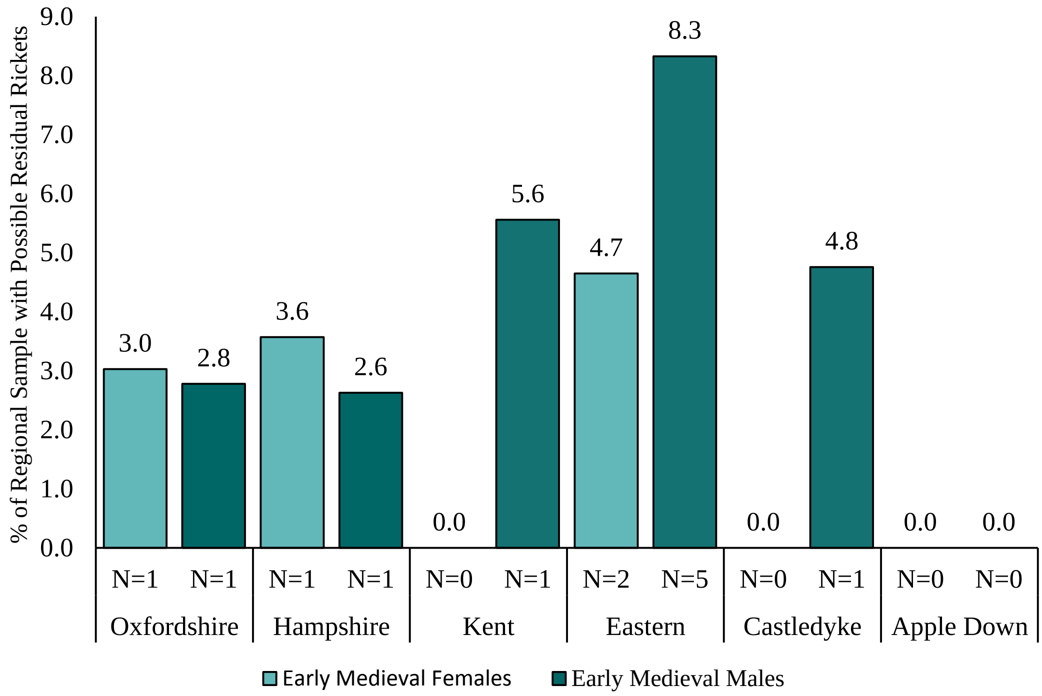


Figure 6.19: *Multiple sites located within similar geographic locations displaying pathological changes associated with residual rickets for Early Medieval females and males.*

6.3.3 Comparison of stress indicators between the Romano-British and Early Medieval Periods

The prevalence of stress indicators was compared between Romano-British and Early Medieval samples to examine diachronic changes during this transitional period. This was performed with the aim to aid in answering research question five. This section will present those categories which were statistically different between sex, age, and geographic locations. All four stress indicators were compared. This could provide valuable insight regarding stress experienced during growth and development between these two periods that may have a bearing on body proportions and adult stature attained.

6.3.3.1 Total Romano-British sample compared to total Early Medieval sample

Comparisons between these two periods demonstrated statistically significant differences in two of the four stress indicators. These differences were detected in the presence of dental enamel hypoplasia (p=0.0001, χ^2=18.99, df=1) and periosteal reactions on the long bones (p=0.0207, χ^2=5.66, df=1). The period with the greatest prevalence of DEH was in the Romano-British sample, whilst the greatest prevalence of periosteal reaction on the long bones occurred in the Early Medieval sample (Fig. 6.20).

Potential differences between age categories within the Romano-British and Early Medieval periods were not pertainent to answering research question five, but were performed to detect potential differences. Significant differences between these two periods were discovered in the frequency of dental enamel hypopolasia between two age categories: 18-25 years and 26-45 years (Table 6.19). Due to the small sample size of individuals within the Romano-British sample exhibiting periosteal new bone formation and possible residual rickets, a statistical comparison of the two periods was not undertaken.

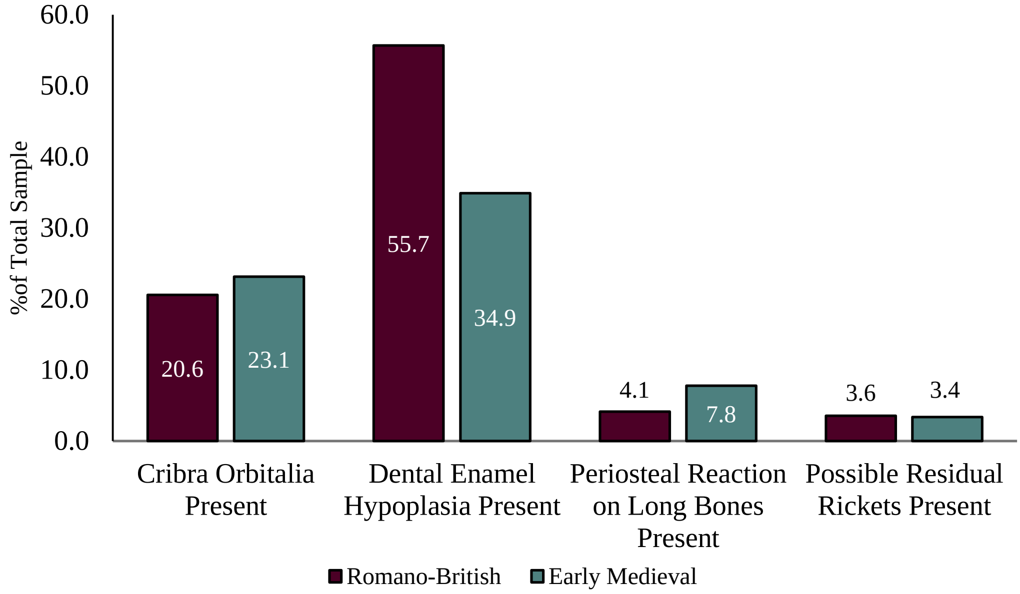


Figure 6.20: *Percentage of total Romano-British and Early Medieval samples affected by the four stress indicators assessed (cribra orbitalia, dental enamel hypoplasia, periosteal new bone formation, and possible residual rickets).*

Table 6.19: *Statistically significant differences between Romano-British and Early Medieval populations with regard to various stress indicators in different age categories. Bonferroni-corrected α=0.0100*

Stress Indicator	18-25 Years	26-45 Years
Dental Enamel Hypoplasia	$p=0.0003$ $\chi^2=13.09$ f=1	$p<0.0001$ $\chi^2=23.69$ df=1

The grouping of the 15 archaeological sites dating to the Early Medieval period into six regional categories were utilized when comparing the Early Medieval sample to the Romano-British sample. Sites and regions located within similar geographic locations were compared to one another to detect possible differences in regions through time. Table 6.20 lists the sites/regions compared to one another with the presence of the four stress indicators recorded during analysis. Statistically significant differences between Romano-British sites and Early Medieval regions are presented in Table 6.21. The Romano-British sample had a statistically greater prevalence of dental enamel hypoplasia (Fig. 6.21). Though statistical comparison of periosteal new bone formation could not be performed due to small sample sizes, those from the Early Medieval period demonstrated a higher prevalence than Romano-British from similar geographic locations (Fig 6.22).

Table 6.20: *Comparison of Romano-British sites and Early Medieval regions with the presence of stress indicators.*

Romano-British Sites		**Early Medieval Regions**
Queensford Farm/Mill	vs	Oxfordshire
Roman Suburbs of Winchester	vs	Hampshire
Roman Suburbs of Winchester	vs	Apple Down (Southern region)
Roman Suburbs of Winchester	vs	Kent
Poundbury	vs	Hampshire
Poundbury	vs	Apple Down (Southern region)
Butt Road	vs	Castledyke (Northern region)
Butt Road	vs	Eastern
Roman London	vs	Eastern
Roman London	vs	Oxfordshire

Table 6.21: *Romano-British sites and Early Medeival regions that present statistically significant differences in the presence of DEH. The alpha has been corrected to α=0.005 to account for possible Type I erros by using a Bonferroni-correction. Only sites/regions with statistically significant differences are showed.*

Sites/Region Comparisons	**Chi-Square Tests**
Poundbury vs Hampshire	$p<0.0001$ $\chi^2=32.16$ df=1
Poundbury vs Apple Down	$p<0.0001$ $\chi^2=14.07$ df=1
Butt Road vs Castledyke	$p<0.0001$ $\chi^2=34.22$ df=1
Butt Road vs Eastern	$p<0.0001$ $\chi^2=17.83$ df=1
Roman London vs Oxfordshire	$p<0.0001$ $\chi^2=13.01$ df=1

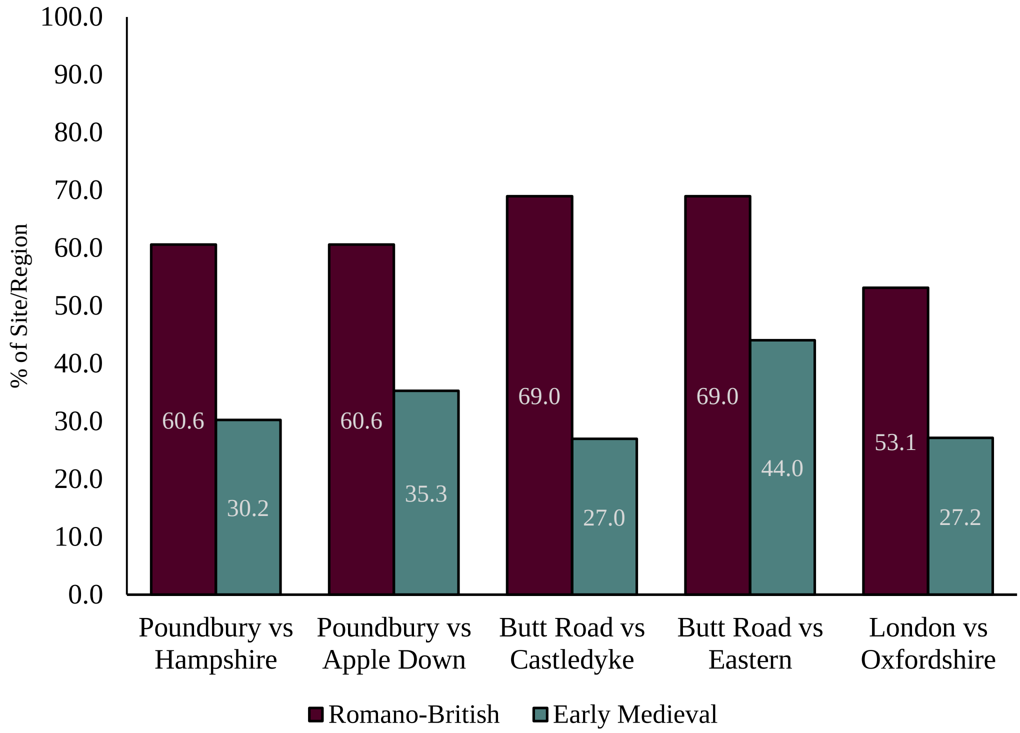


Figure 6.21: *Percentage of Romano-British sites and grouped Early Medieval sites into regions displaying statistically significant differences in the presence of DEH.*

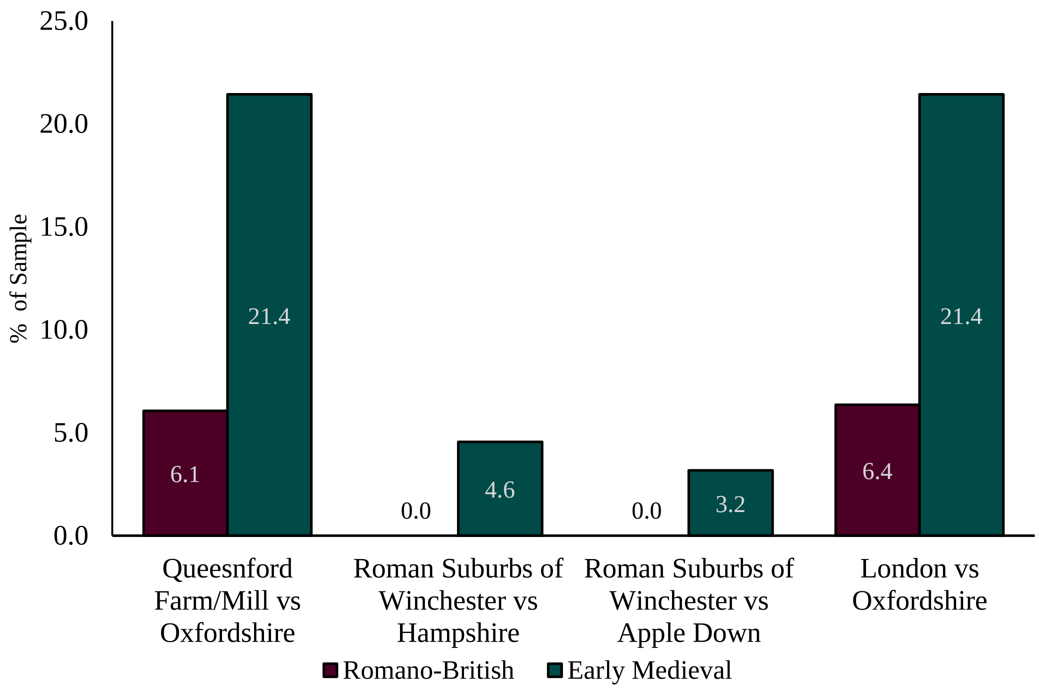


Figure 6.22: *Percentage of sample demonstrating periosteal new bone formation of Romano-British sites and sites grouped into geographic regions in Early Medieval sample. A greater prevalence is noted within the Early Medieval sample.*

6.3.3.2 Comparison of females from Romano-British and Early Medieval samples

Only one stress indicator was statistically different between females from these two periods: dental enamel hypoplasia (Fig 6.23). A greater proportion of Romano-British females demonstrated dental enamel hypoplasia (p=0.0053, χ^2=8.01, df=1) than in the later period. Using Bonferroni-corrected alpha (α=0.0100) significant differences between these two samples occurred with the presence of dental enamel hypoplasia within the 18-25 year (p=0.0100, χ^2=8.05, df=1) and 26-45 year age categories (p=0.0100, χ^2=7.11, df=1). Females from the Romano-British period demonstrated a greater percentage of dental disease and cribra orbitalia than those from the Early Medieval period, (Fig. 6.24). The same sites/regions within the total sample demonstrated statistically significant differences in the presence of dental enamel hypoplasia within the female sample, however only females from Poundbury and Apple Down (p=0.0006, χ^2=11.7, df=1) and Butt Road and Castledyke (p=0.0001, χ^2=15.8, df=1) showed statistically significant differences (Bonferroni, α=0.0005), with Romano-British females presenting a higher prevalence of DEH (Fig. 6.25).

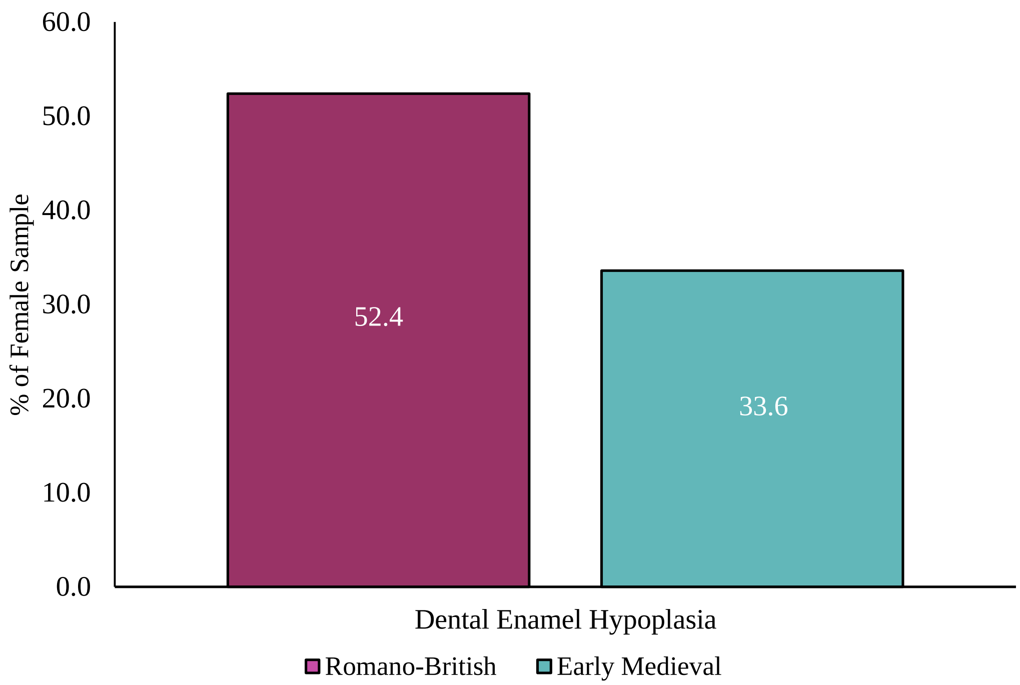


Figure 6.23: *Percentages of Romano-British and Early Medieval females displaying DEH.*

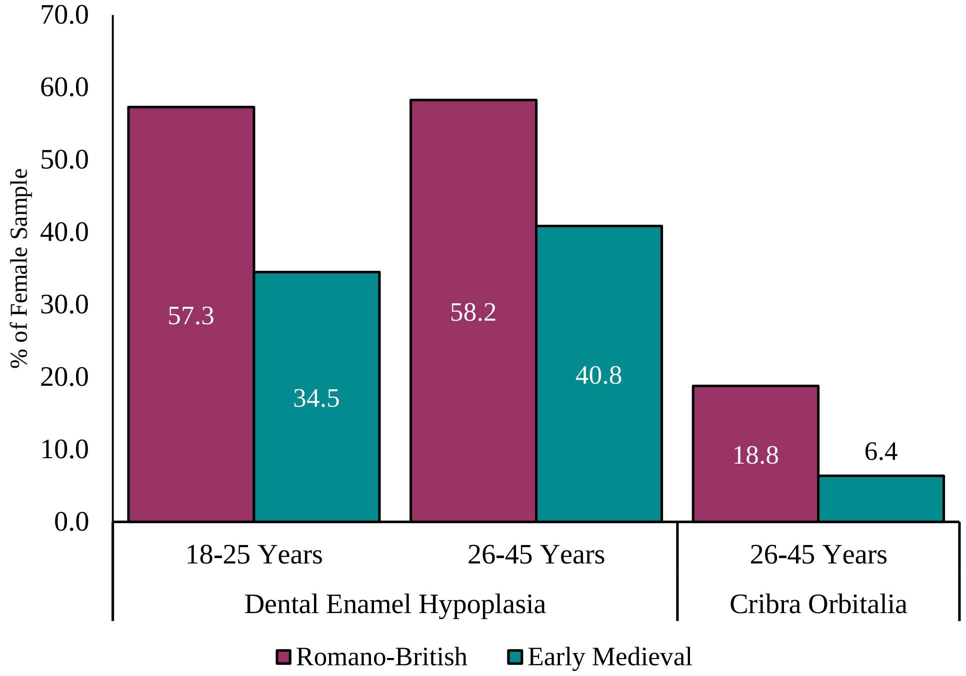


Figure 6.24: *Percentages of Romano-British and Early Medieval females displaying statistically significant differences in the presence of DEH and cribra orbitalia in each age category.*

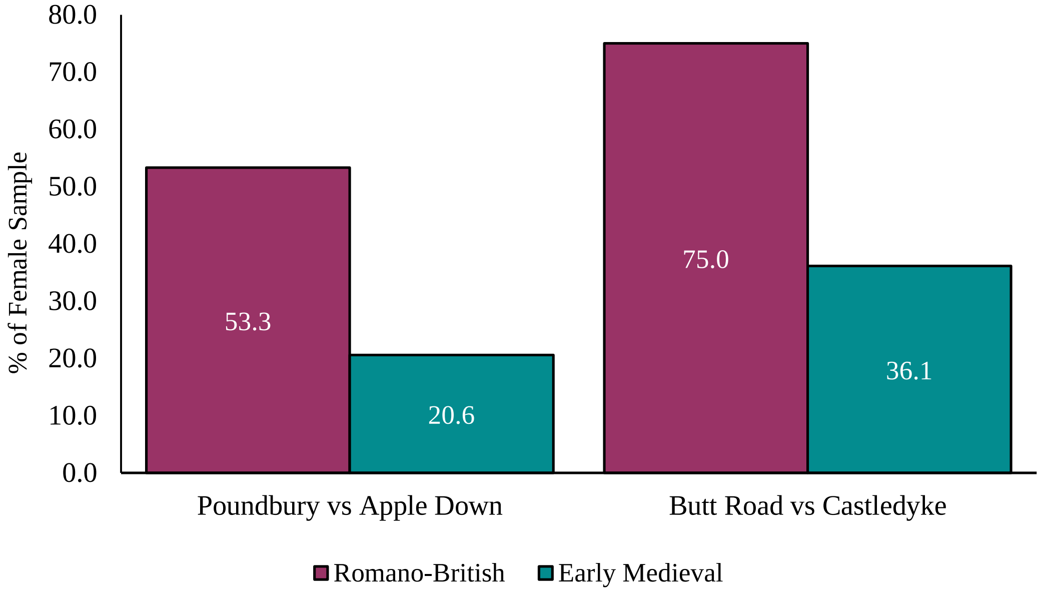


Figure 6.25: *Percentages of Romano-British and Early Medieval females demonstrating statistically significant differences in the prevalence of DEH between sites/regions.*

6.3.3.3 Romano-British male sample comparison to Early Medieval male sample

For the males, only DEH was determined to be statistically different between periods (p=0.0017, χ^2=10.41, df=1). Romano-British males displayed a statistically greater prevalence of DEH compared to the later period (Fig. 6.26). Comparisons between age categories found a statistically significant difference in the age category of 26-45 years only (p=0.0010, χ^2=15.90, df=1) using a Bonferroni-corrected alpha (α=0.0100) with males from the Romano-British sample displaying a higher prevalence in each age category (Fig.6.27). Statistically significant differences with the presence of dental enamel hypoplasia were noted between the same sites and regions as the female sample (see Appendix 2 Table 82), with the exception of a difference between Roman London and Early Medieval Eastern region (Fig. 6.28).

6.3.4 Summary

Overall, there is a general increase in the presence of DEH between the Romano-British and Early Medieval samples analysed. This was not only seen between sexes, but age categories and geographic locations. Although a slight increase was discovered in the presence of CO between the two periods, this increase was not significant.

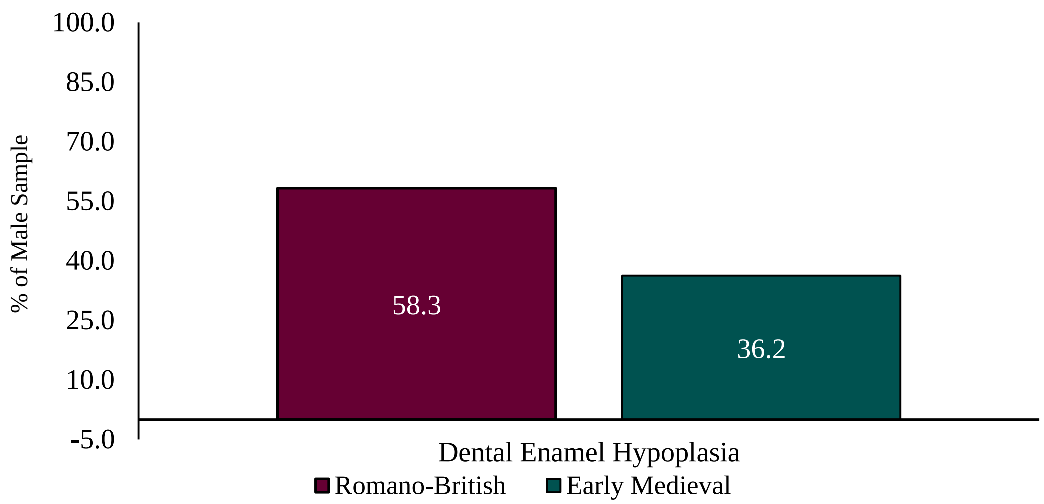


Figure 6.26: *Percentage of Romano-British and Early Medieval males displaying DEH.*

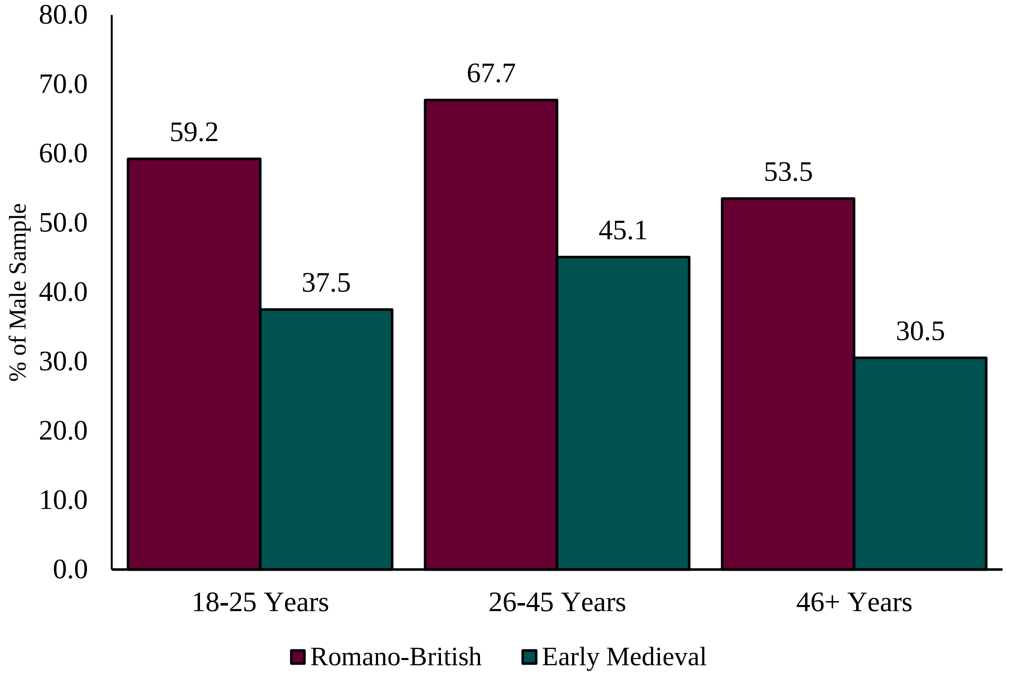


Figure 6.27: *Percentage of Romano-British and Early Medieval males displaying statistically significant differences in DEH within each age category.*

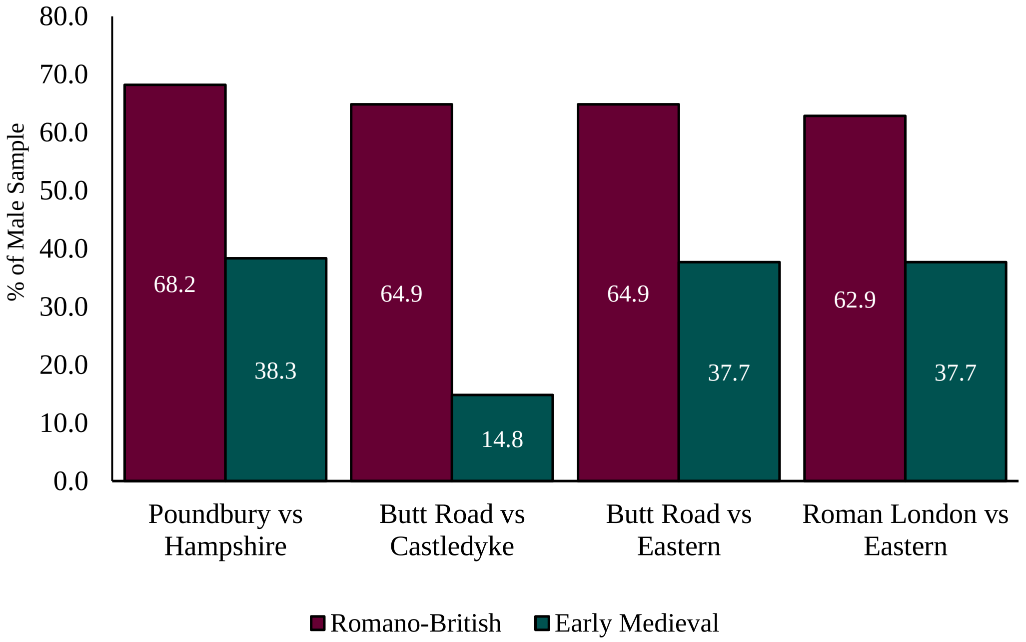


Figure 6.28: *Percentage of Romano-British and Early Medieval males displaying statistically significant differences in the presence of DEH between various sites/regions.*

6.4 Stature Estimation of Romano-British and Early Medieval Populations

This section will focus on the stature of all individuals within the Romano-British and Early Medieval samples. In order to investigate research questions one and two, comparisons between the Fully anatomical methods and relevant mathematical regression equations were made and tested. This aids in determining which method produces the most accurate and reliable stature estimations for these samples. Stature will be compared between females and males, various age categories, as well regions and periods to fully examine and explore with the aim of answering research questions four and six.

6.4.1 Stature using the Fully anatomical method

To calculate stature using the Fully anatomical method, a total of 29 skeletal elements must be present in each individual. From the 758 Romano-British and 490 Early Medieval skeletons analysed, only 35 individuals from the earlier period (18 females and 17 males) and 12 individuals from the later period (three females and nine males) had all of the necessary skeletal elements required for the Fully anatomical method. Living stature for these 47 individuals was calculated using the revised Fully anatomical method suggested by Raxter *et al*. (2006, 2007). According to Raxter *et al.* (2006, 2007), an age correction should also be applied when estimating living stature from human skeletal remains, as overall stature generally decreases with age. In archaeological material, age is often given in 10 or 20 year age ranges, thus it was recommended by Raxter *et al.* (2007) that midpoints of these age ranges be used in the age-adjusted formulae. Within this study, these midpoints would be 21.5 years for the 18-25 year age category and 35.5 years for the 26-45 year age category. The 20 year age range was deemed acceptable as Raxter *et al.* (2008) used a wider age range of 30 years to calculate living stature in their Ancient Egyptian sample. Raxter *et al.* (2006) provided a second formula to estimate stature if age was unknown. This formula utilized cadaveric measurements of an older, modern population; therefore the stature for individuals over the age of 46 years or aged as ADULT were calculated using the unadjusted age formula as it most likely reflects this sample. Prior to applying a soft tissue correction to stature, skeletal height must be calculated by summing measurements from all 29 skeletal elements that contribute towards an individual's height. Next, the skeletal height is entered in the following equations (age-adjusted and unadjusted age recommended by Raxter *et al.* (2006, 2007):

Age-Adjusted:

$$living\ stature = 1.009\ X\ Skeletal\ height\ (cm) - 0.0426\ X\ Average\ age + 12.1$$

Age-Unadjusted:

$$living\ stature = 0.996\ X\ Skeletal\ height(cm) + 11.7$$

Using the soft-tissue correction instead of the skeletal height is standard practice in recent studies focusing on stature (e.g. Raxter *et al.*, 2006). The mean stature for Romano-British females was 155.8 cm and 164.3 cm for males, whilst the mean for Early Medieval females was 156.2 cm and 170.1 cm for Early Medieval males. Ranges in stature can be found in Figure 6.29. All box and whiskers plots throughout the results and discussion represent the median, interquartile range, as well as the maximum and minimum calculated stature for each sample. The following sections will discuss those skeletal elements missing most frequently in these samples and the methods by which values for missing skeletal elements can be estimated in order to increase sample size.

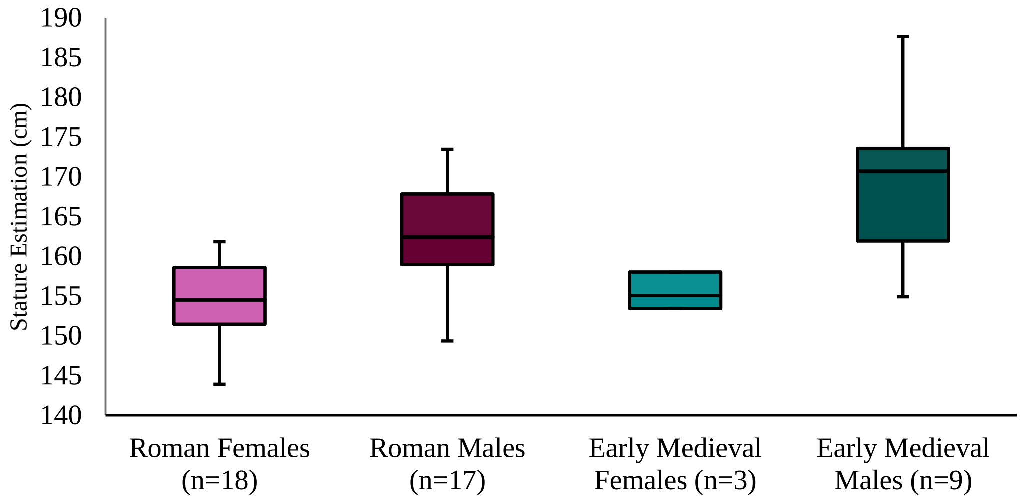


Figure 6.29: *Box and whisker plots demonstrating Romano-British and Early Medieval stature estimated using the revised Fully anatomical method (Raxter et al., 2006, 2007).*

6.4.1.1 Human skeletal elements present in both samples

The skeletal element least likely to be sufficiently well-preserved for measurement in both samples was the cranium, which was present in only 35% of the Romano-British females, 33% of the Romano-British males, 18% of Early Medieval females, and 22% of Early Medieval males (Appendix 3 Table 1 and Fig. 1). Unsurprisingly, skeletal elements in the upper portion of the axial skeleton were missing more frequently than those in the lower axial and appendicular skeleton.

When employing the revised Fully anatomical method, Raxter *et al.* (2006, 2007), suggested that vertebral bodies demonstrating the presence of marginal osteophytes must be discounted as this pathology could affect the calculation of living stature by overestimating final height. Here, however, individuals with marginal osteophytes were removed from the sample *only if* these affected the vertebral height measurement, which in most instances was not the case. As demonstrated in Figure 6.30, when more skeletal elements are added to estimate stature using the Fully anatomical method (starting with the cranium), the number of potential individuals with a stature estimation within the sample sharply decreases. In order to increase the number of individuals available for stature calculation using the Fully anatomical method, the estimation of missing skeletal elements is crucial.

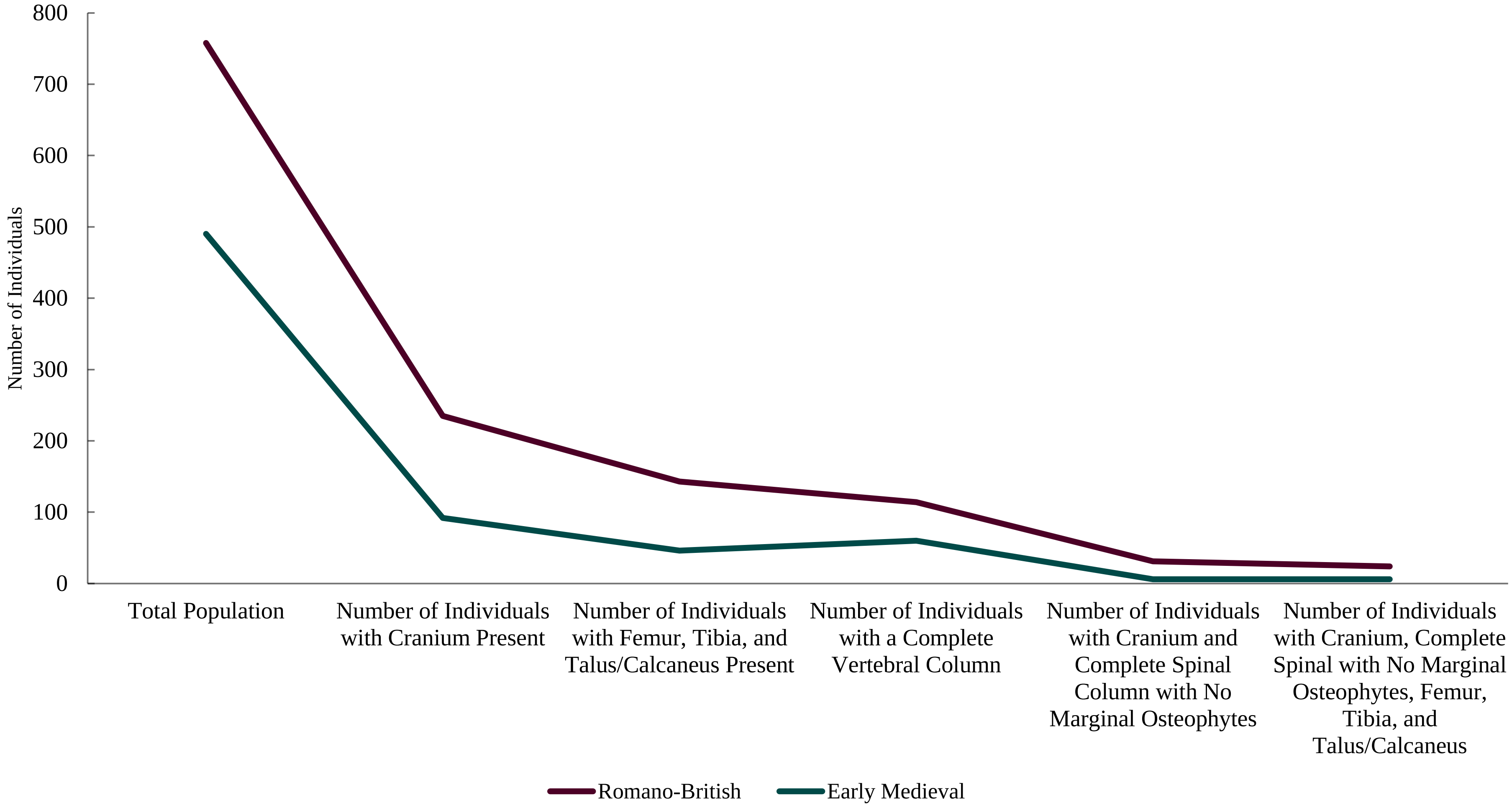


Figure 6.30: *Decreasing sample size for the Fully anatomical Method with increase in skeletal elements needed.*

6.4.1.2 Estimation of missing skeletal elements

In order to calculate stature using the Fully anatomical method, it is necessary to estimate the dimensions of missing elements. This was undertaken using methods devised by Auerbach (2011) and other methods specifically developed on this sample (see Section 5.4.1, Chapter Five). Auerbach (2011) found that estimating cranial height using linear regression equations created from known measurements did not yield accurate or reliable estimations of this measurement. Similar to Auerbach's assessment, multiple and single regression formulae were created from known measurements of females and males from both periods in order to estimate cranial height (Table 6.22). All regression formulae produced low reliability (r^2) and standard errors greater than the TEM for cranial height (0.22 mm) (see section 5.3.2 of Chapter Five). Therefore, cranial height could not be estimated from known measurements of post-cranial elements.

Table 6.22: *Single and multiple regression estimating cranial (Bregma-Basion) height from measured postcranial elements.*

Romano-British Females	r^2	**Adjusted** r^2	**Standard Error (cm)**
Multiple Regression of Postcranial Elements			
All Seven Postcranial Elements	0.61	0.34	3.15
Single Regression of Postcranial Elements			
SUM of Cervical Vertebrae	0.003	-0.06	3.99
SUM of Thoracic Vertebrae	0.03	-0.03	3.94
SUM of Lumbar Vertebrae	0.27	0.22	3.42
S1 Height	0.18	0.13	3.62
Femur Physiological Length	0.02	-0.04	3.95
Tibia (Maximum)	0.15	0.10	3.68
Talus/Calcaneus	0.05	-0.01	3.90
Romano-British Males	r^2	**Adjusted** r^2	**Standard Error (cm)**
Multiple Regression of Postcranial Elements			
All Seven Postcranial Elements	0.61	0.30	12.88
Single Regression of Postcranial Elements			

SUM of Cervical Vertebrae	0.21	0.16	14.14
SUM of Thoracic Vertebrae	0.02	-0.05	15.79
SUM of Lumbar Vertebrae	0.0003	-0.07	15.93
S1 Height	0.001	-0.07	15.78
Femur Physiological Length	0.02	-0.05	15.79
Tibia (Maximum)	0.04	-0.02	15.59
Talus/Calcaneus	0.05	-0.01	15.53
Early Medieval Females	r^2	**Adjusted** r^2	**Standard Error (cm)**
Multiple Regression of Postcranial Elements			
All Seven Postcranial Elements	N/A	N/A	N/A
Single Regression of Postcranial Elements			
SUM of Cervical Vertebrae	0.002	-1.00	1.63
SUM of Thoracic Vertebrae	0.74	0.49	0.83
SUM of Lumbar Vertebrae	0.13	1.53	-0.75
S1 Height	0.0005	-1.00	1.63
Femur Physiological Length	0.95	0.90	0.35
Tibia (Maximum)	0.03	-0.94	1.61
Talus/Calcaneus	0.20	-0.59	1.46
Early Medieval Males	r^2	**Adjusted** r^2	**Standard Error (cm)**
Multiple Regression of Postcranial Elements			
All Seven Postcranial Elements	0.99	0.94	0.95
Single Regression of Postcranial Elements			
SUM of Cervical Vertebrae	0.27	0.17	3.53
SUM of Thoracic Vertebrae	0.39	0.30	3.23
SUM of Lumbar Vertebrae	0.35	0.26	3.33
S1 Height	0.05	-0.09	4.04
Femur Physiological Length	0.44	0.36	3.10
Tibia (Maximum)	0.40	0.31	3.22
Talus/Calcaneus	0.21	0.09	3.69

Skeletal elements from the vertebral column were missing in 57% of the 1248 individuals. Auerbach (2011) created two methods to estimate total vertebral column length from the known vertebral body heights present in a sample. To test the accuracy of these methods, complete vertebral columns from the Romano-British and Early Medieval periods were used. The first method estimated single vertebral body heights using the mean of known maximum vertebral body heights from adjacent (superior and inferior) vertebrae. This method did not reliably predict several maximum vertebral body heights, particularly those of C3, C6, T2, and T11. The vertebrae that had a statistically significant difference between the measured maximum vertebral body height and estimated vertebral body height based on paired *t*-test in Romano-British females and males as well as Early Medieval females and males are presented in Appendix 3 Table 2 due to the large size of the table. A total of 21 pairwise *t*-tests were computed to detect statistically significant differences between measured and estimated single vertebral body heights per group (e.g. Romano-British females or Early Medieval males). Due to the large number of tests undertaken, a Bonferroni-corrected alpha level was utilized to prevent Type I errors when using pairwise *t*-tests to determine if any statistically significant difference between measured individual vertebrae and estimated vertebrae using Sciulli *et al.* 1990 method of estimating single vertebral body heights from adjacent vertebrae. The adjusted alpha level of statistical significance was determined to be $\alpha=0.002$. Root mean square errors were calculated for each vertebra, with many exhibiting values greater than one millimetre (Appendix 3, Table 2), demonstrating larger ranges from measured vertebrae.

Auerbach (2011) found similar results in estimating vertebral body heights using adjacent vertebrae and therefore constructed regression formulae to estimate the maximum vertebral body heights of C2, C3, C6, T2, T11, L1, and L5 for both females and males. These 14 equations (Appendix 3 Table 3) were assessed to determine their accuracy in estimating maximum vertebral body heights for individuals dating to the periods concerned in this thesis. Paired *t*-test results are presented in Table 6.23. These regression equations did not accurately estimate maximum height for C2 in either Romano-British and Early Medieval females and males. Within the Romano-British female sample, the equations for estimating the maximum vertebral body heights of T11 and L1 were statistically different from the known measurements, whilst the equation for estimating L1 was significantly different in the Romano-British male sample. The only vertebra within the Early Medieval female and male samples that was not accurately estimated was the vertebral body height of C2. The mean differences between the known and estimated vertebrae were greater than the technical error of measurement (section 5.4.2, Chapter Five) and in some estimations, was greater than 0.50 mm for both Roman-British and Early Medieval periods. A Bonferroni-corrected alpha (α=0.0070) was used to account for Type I errors as seven paired *t*-tests were used for each sample group.

Table 6.23: *Estimation of individual vertebral body heights (mm) from multiple regression equations within Table 5 of Auerbach (2011). Paired t-test with statistically significant differences between measured and estimated vertebral body height within shaded cells. "K"=known mean measurement, MD= Mean difference, Cal = Calculated mean value, t-test=Paired t-test.*

Vert.	**Romano-British Females (n=47)**			**Romano-British Males (n=65)**			**Early Medieval Females (n=28)**			**Early Medieval Males (n=32)**		
	K	Cal	t-test	K	Cal	t-test	K	Cal	t-test	K	Cal	t-test
C2	36.4	34.7	p<0.0001	39.0	37.7	p<0.0001	37.6	34.2	p<0.0001	40.7	38.0	p<0.0001
MD	-1.8		t=9.0	-1.3		t=-4.8	-3.4		t=7.2	-2.7		t=6.1
C3	12.3	12.4	p=0.6477	13.4	13.6	p=0.0240	12.4	12.5	p=0.3571	13.7	13.8	p=0.7745
MD	0.05		t=-0.5	0.2		t=-2.3	0.1		t=-0.9	0.05		t=-0.3
C6	12.1	12.2	p=0.5973	12.9	13.2	p=0.0707	12.1	11.7	p=0.0201	13.0	13.3	p=0.0841
MD	0.05		t=-0.53	0.2		t=-1.8	-0.4		t=2.0	0.3		t=-1.8
T2	17.4	17.2	p=0.1367	18.2	18.3	p=0.8360	17.1	16.9	p=0.3584	18.7	18.9	p=0.6967
MD	-0.1		t=1.5	0.03		t=-0.2	-0.1		t=0.9	0.2		t=-0.4
T11	22.4	22.0	p=0.0003	22.4	22.5	p=0.9540	21.9	21.7	p=0.0786	23.5	23.4	p=0.5178
MD	-0.4		t=-3.9	0.01		t=-0.06	-0.2		t=1.8	0.08		t=0.7
L1	26.1	25.4	p<0.0001	25.6	25.9	p=0.0040	25.1	24.8	p=0.1668	26.8	26.8	p=0.8919
MD	-0.7		t=6.2	0.3		t=-3.0	-0.3		t=1.4	-0.02		t=0.1
L5	27.9	28.1	p=0.5164	27.9	28.4	p=0.0178	27.2	27.5	p=0.1529	29.3	29.3	p=0.9596
MD	0.1		t=-0.7	0.4		t=-2.4	0.3		t=-1.5	-0.01		t=0.1

Both methods for estimating single vertebrae suggested by Auerbach (2011) failed to accurately estimate a few vertebrae within the samples analysed here, specifically regarding C2. Considering this and the importance of being able to estimate missing vertebral elements, a new method was created to account for the curvature of the spine (Section 5.5.1 Chapter Five). The linear regression utilizes a calculated "k-coefficient" (which has been calculated for each vertebra) and considers the variation in vertebral body heights of individual vertebrae due to the curvature of the spinal column. Estimations of all vertebrae through this method yielded no statistically significant differences between the measured and estimated vertebral body heights (Appendix 3,

Table 4), meaning the means are statistically indistinguishable, which is expected considering this method was constructed from these measurements. Therefore, root mean squared error (RMSE) was calculated for each vertebra to determine how much these calculations vary. Most RMSEs were under one millimetre (Appendix 3, Table 4). It is recognized that no method will be perfect in estimating missing vertebral skeletal elements along with elements of uncertainty, however the method presented here demonstrates lower RMSE than the adjacent vertebrae method outlined above. The application of this new method for estimating the maximum body height of missing vertebrae from known adjacent vertebral measurements enabled the inclusion of a further 43 individuals from the Romano-British period and 22 individuals from the Early Medieval period to the sample (Table 6.24).

Table 6.24: *Number of individuals with a complete vertebral column added with the estimation of adjacent vertebrae.*

Population	**Complete Vertebral Column**	**Estimated Adjacent Vertebrae**	**Total**
Romano-British Females	47	15	62
Romano-British Males	67	28	95
Early Medieval Females	30	9	39
Early Medieval Males	35	13	48

The second set of methods devised by Auerbach (2011) to estimate missing measurements within the vertebral columns employed multiple regression formulae from known vertebral column measurements to estimate missing vertebral sections. These formulae, originally published in Auerbach (2011), are presented in Appendix 3 Table 5. This allowed for the calculation of missing cervical regions and combined cervical and thoracic regions from measured thoracic and lumbar sections and measured lumbar sections, respectively. Two sets of equations were created for each region estimated; one equation estimated the section of vertebrae missing, whilst the second equation estimated the length of the entire vertebral column. To determine whether Auerbach's (2011) four formulae would accurately estimate missing cervical and thoracic regions in the Romano-British and Early Medieval samples, known vertebral sections and total column length from each period were compared to calculated vertebral sections and total vertebral column length. Although the Romano-British and Early Medieval vertebral sections were statistically different between females and males in some vertebral regions (Table 6.25), the equation proposed by Auerbach (2011) combines the sexes. Paired *t*-tests and Wilcoxon tests examined potential statistically significant differences between known and estimated vertebral sections and total vertebral column length. Unfortunately, the equations offered by Auerbach (2011) were not successful in estimating missing vertebral regions and total vertebral column length in the Romano-British sample and the cervical equations for the Early Medieval sample. Since Auerbach's (2011) equations did not accurately estimate missing cervical, or total vertebral column lengths in both samples (Table 6.26), new population specific regression formulae were created from the 114 and 64 known Romano-British and Early Medieval vertebral columns, respectively. The statistically significant differences found between females and males in both samples (Table 6.25) meant that female and male specific equations were required for each period. These formulae were developed from 47 Romano-British females, 67 Romano-British males, 30 Early Medieval females, and 35 Early Medieval males.

Table 6.25: *Student's t-test comparing differences between the percentage of vertebral regions from the total vertebral column amongst Romano-British (RB) and Early Medieval (EM) females and males. Shaded cells demonstrate statistically significant differences between females and males within the same period. Bonferroni-corrected α=0.0125.*

Pop.	**Percentage of Cervical Vertebrae**	**Percentage of Thoracic Vertebrae**	**Percentage of Lumbar Vertebra**	**Total Vertebral Column Length**
RB	t=-5.75 p<0.0001	t=-1.32 p=0.1882	t=11.92 p<0.0001	t=-8.33 p<0.0001
EM	t=-1.74 p=0.0826	t=-2.35 p=0.0192	t=3.43p =0.0002	t=-8.85 p<0.0001

Table 6.26: *Statistical analysis of Auerbach's (2011) multiple regression equations calculating missing cervical, cervical and thoracic, and total vertebral column length. Shaded cells represent statistically significant differences between known and estimated vertebral sections based on paired t-tests or +Wilcoxon test. Cerv. Sect=cervical section, Cerv+Thor=cervical section + thoracic section, TC=total column length with cervical section, TCT=total column length with cervical and thoracic sections, K=known length (mm), Est=Estimated length using Auerbach's (2011) equation (mm) MD= Mean difference between the known length and estimated length of vertabral sections. Bonferroni-corrected α=0.0125.*

Vertebral Sect.	**Romano-British**					**Early Medieval**				
	K	Est	MD	*t* or W	p-value	K	Est	MD	*t*	p-value
Cerv Sect	103.3	99.5	3.8	6.8	<0.01	104.2	100.3	3.9	6.4	<0.01
Cerv+ Thor	339.0	338.3	0.73	3628+	0.32+	342.6	339.0	3.6	2.1	0.04
TC	475.6	469.9	5.6	-10.4	<0.01	479.5	473.7	5.8	9.5	<0.01
TCT	475.6	471.86	3.74	4347+	0.002+	479.5	475.9	3.6	2.1	0.04

Using ordinary least squares (OLS), regression formulae were created (see Appendix 3 Figures 2-9). These formulae are presented in Table 6.27. Equations with smaller percent standard error of the estimate (%SEE) are regarded to be more accurate. Based on this information, equations that estimate the entire vertebral column from specific vertebral sections were more accurate than estimating vertebral sections and adding the remaining measured vertebral sections to estimate the total vertebral column length, a result similar to Auerbach's. The regression equation estimating the total vertebral column length from the length of the thoracic and lumbar vertebrae had a smaller standard deviation and standard error than estimating the total vertebral column length from the lumbar section only, therefore estimating total column length from the former should be undertaken when possible. These equations were used to incorporate a greater number of individuals into the sample to have stature estimated using the Fully anatomical method. When analysed as four complete groups (Romano-British females and males, Early Medieval females and males), no outliers were discovered with regard to total vertebral column length. This result includes those columns with estimated individual vertebrae and those estimated using the regression equations described in Table 6.27. Error associated with utilizing these equations (SEE) is less than the errors associated with Auerbach's (2011) missing vertebral region equations (Appendix 3 Table 5).

To statistically examine the formulae created using known (measured) Romano-British and Early Medieval vertebral columns, known vertebral column regions and total column lengths were compared to those calculated using the formulae presented in Table 6.27 using paired *t*-tests. No statistically significant differences were found in the estimations of vertebral regions using the formulae created for these sample populations. These equations were able to estimate the cervical vertebral region, the cervical and thoracic vertebral regions, and total column height from the summed thoracic and lumbar or lumbar only measurements. All critical values (p) were above 0.99. These results can be found in Table 6.28. The only way to examine definitely whether these equations produce accurate estimates is to use the 'leave one out cross validation' method, however for the purposes of this research it was deemed unnecessary.

Table 6.27: *Multiple regression equations for the estimation of cervical, cervical and thoracic, and total vertebral column lengths from known thoracic and lumbar and lumbar maximum vertebral body height measurements for Romano-British and Early Medieval females and males. Coefficients of reliability, standard error of estimators, mean differences between known and estimated measurements, 95% confidence intervals, standard deviations, and standard errors are also presented within the table. All equations are in mm.*

	Estimated Vertebral Section	**Estimator(s)**	**Equations**	***r***	**SEE (%SEE)**	**Mean Difference**	**95% Confidence Intervals** Lower	Upper	**Standard Deviation**	**Standard Error**
Romano-British Females (n=47)	Cervical	Sum of Thor and Sum of Lum Vert	0.2216(Thoracic) + 0.058786(Lumbar) +39.33	0.49	4.72 mm (4.79%)	-0.000342	-1.32	1.32	4.63	0.67
	Vertebral Column	Sum of Thor and Sum of LumVert	1.2216(Thoracic) + 1.0588(Lumbar) +39.33	0.97	4.72 mm (1.01%)	0.001566	-1.32	1.32	4.63	0.67
	Cervical and Thoracic	Sum of Lum Vert	1.0395(Lumbar) + 188.62	0.61	11.07 mm (3.35%)	0.006881	-3.12	3.14	10.95	1.60
	Vertebral Column	Sum of Lum Vert	2.0395(Lumbar) + 188.62	0.84	11.07 mm (2.37%)	0.006881	-3.12	3.14	10.95	1.60
Romano-British Males (n=67)	Cervical	Sum of Thor and Sum of LumVert	0.080147(Thoracic) + 0.34934(Lumbar) +39.92	0.62	5.15 mm (4.83%)	0.000539	-1.21	1.21	5.05	0.61
	Vertebral Column	Sum of Thor and Sum of LumVert	1.0801(Thoracic) + 1.3493(Lumbar) +39.92	0.98	5.14 mm (1.07%)	-0.016143	-1.22	1.19	5.05	0.62
	Cervical and Thoracic	Sum of Lum Vert	1.8165(Lumbar) + 98.87	0.86	9.55 mm (2.76%)	0.001188	-2.27	2.27	9.48	1.16

	Vertebral Column	Sum of Lum Vert	2.8165(Lumbar) + 98.87	0.93	9.55 mm (1.98%)	0.001188	-2.27	2.27	9.48	1.16
Early Medieval Females (n=30)	Cervical	Sum of Thor and Sum of Lum Vert	0.182606(Thoracic) + 0.256197(Lumbar) + 23.99	0.50	4.91 mm (4.94%)	$-9.74*10^{-6}$	-1.72	1.72	4.82	0.88
	Vertebral Column	Sum of Thor and Sum of Lum Vert	0.182606 (Thoracic) + 0.256197(Lumbar) + 23.99	0.96	4.91 mm (1.07%)	-0.001225	-1.72	1.72	4.82	0.88
	Cervical and Thoracic	Sum of Lum Vert	1.1134(Lumbar) + 178.90	0.55	10.48 mm (3.21%)	-0.003820	-3.69	3.68	10.29	1.88
	Vertebral Column	Sum of Lum Vert	2.1134(Lumbar) + 178.90	0.78	10.48 mm (2.28%)	$5.94*10^{-5}$	-3.68	3.68	10.29	1.88
Early Medieval Males (n=35)	Cervical	Sum of Thor and Sum of Lum Vert	0.220177(Thoracic) + 0.069748(Lumbar) + 44.54	0.67	4.27 mm (3.92%)	$-8.12*10^{-5}$	-1.40	1.40	4.18	0.72
	Vertebral Column	Sum of Thor and Sum of Lum Vert	1.220177(Thoracic) + 1.069748(Lumbar) + 44.54	0.99	4.27 mm (0.86%)	$-8.12*10^{-5}$	-1.40	1.40	4.18	0.72
	Cervical and Thoracic	Sum of Lum Vert	1.957059(Lumbar) + 81.22088	0.83	11.13 mm (3.12%)	$3.06*10^{-5}$	-3.63	3.62	10.79	1.85
	Vertebral Column	Sum of Lum Vert	2.957059(Lumbar) + 81.22088	0.91	11.13 mm (2.24%)	$3.06*10^{-5}$	-3.62	3.62	10.79	1.85

Table 6.28: *Statistical analysis of multiple regression equations calculating missing cervical, cervical and thoracic, and total vertebral column length against known (measured) Romano-British and Early Medieval vertebral columns. . Cerv. Sect=cervical section, Cerv+Thor=cervical section added with thoracic section, TC=total column length with cervical section, TCT=total column length with cervical and thoracic sections, K=known length (mm), Est=Estimated length equation (mm) MD= Mean difference between the known length and estimated length of vertebral sections.*

Vertebral Sect.	**Romano-British Females (n=47)**					**Romano-British Males (n=67)**				
	K	Est	MD	t	p	K	Est	MD	t	p
Cerv Sect	98.7	98.7	$3.4*10^{-4}$	$5.1*^{10-4}$	0.999	106.6	106.6	$5.4*10^{-4}$	$-8.8*10^{-4}$	0.999
Cerv+ Thor	330.3	330.3	0.007	-0.004	0.997	345.8	345.8	0.001	-0.001	0.999
TC	466.7	466.7	0.001	-0.002	0.998	481.8	481.8	-0.016	0.026	0.979
TCT	466.7	466.7	0.007	-0.004	0.997	481.8	481.8	0.001	-0.001	0.999
Vertebral Sect.	**Early Medieval Females (n=30)**					**Early Medieval Males (n=35)**				
	K	Est	MD	t or W	p	K	Est	MD	t	p
Cerv Sect	99.5	99.5	$9.7*10^{-6}$	$1.1*10^{-5}$	0.999	108.9	108.9	$-8.1*10^{-5}$	$1.1*10^{-4}$	0.999
Cerv+ Thor	326.7	326.7	0.004	0.002	0.998	356.7	356.7	$3.1*10^{5}$	$-1.7*10^{-5}$	0.999
TC	459.5	459.5	0.001	0.001	0.998	497.4	497.4	$-8.1*10^{-5}$	$1.1*10^{-4}$	0.999
TCT	459.5	459.5	$5.9*10^{-5}$	$-3.2*10^{-5}$	0.999	497.4	497.4	$3.1*10^{5}$	$-1.7*10^{-5}$	0.999

Along with cranial height and spinal column estimates, Auerbach (2011) created regression formulae to reconstruct the bicondylar measurement of the femur, maximum tibial length, and articulated calcaneus/talus height. Estimation of these missing skeletal elements was not assessed as part of this thesis. Regression formulae created in Auerbach's publication reflect Native American body proportions, which may not accurately estimate lower limb proportions of Romano-British or Early Medieval females and males. The reconstruction of these measurements required the presence of both the femur and tibia, which in many cases were not available. Also of concern was the standard error associated with calculating missing elements, which may introduce a greater amount of error in the final stature calculation, therefore no attempt was made to create new formulae specifically for these samples.

Summary:

- Cranial height could not be accurately estimated from post-cranial elements, Auerbach's (2011) proposed formulae for estimating missing individual vertebrae and missing vertebral sections were not accurate for the Romano-British and Early Medieval samples.
- New linear equations using a calculated "k-coefficient" to estimate missing individual vertebral body heights from adjacent vertebrae were produced. These provided a further 65 individuals available to have stature calculated using the Fully anatomical method.
- Auerbach's formulae for estimating missing vertebral sections were inappropriate for the Romano-British and Early Medieval samples. New multiple regression formulae were created from known complete vertebral columns in the sample. The use of these formulae (known thoracic and lumbar measurements) allowed the addition of 231 individuals.
- Unsurprisingly, no statistically significant differences were discovered between the estimated and measured vertebral regions as the comparisons using paired *t*-tests examine differences between means, as the means will be similar when comparing the known measurement to estimated measurement using the same sample.

6.4.1.3 Romano-British stature estimation utilizing the Fully anatomical method

Raxter *et al.* (2006, 2007) discovered that, despite a correlation between calculated stature and living stature when using the Fully (1956) method, the equation underestimated stature by a mean of 2.4 cm. The authors therefore created two new equations, one estimating stature when the age of an individual was unknown and one correcting for age related changes in stature. When they compared their estimated stature with the reported stature within their sample, the maximum difference between the two was 4.5 cm (see Chapter Three). Raxter *et al.* (2007) recommended the use of mean age in an age-correction equation to estimate living stature more accurately. To evaluate the possible differences between age-adjusted and non-age-adjusted stature, Romano-British individuals with measurable skeletal elements from the 29 bones previously mentioned were calculated using both formulae. A total of 35 individuals (18 female and 17 male) had all of the measurable skeletal elements necessary to estimate stature. Those for which vertebral column height was estimated were not used here. Both the female ($p<0.01$) and male ($p<0.01$) samples demonstrated a statistically significant difference between age-adjusted and non-age-adjusted formulae when using paired *t*-tests. Therefore, the age-adjusted formula (presented earlier) was used to calculate stature when mean age can be assessed.

The number of additional individuals available for analysis when estimating vertebral body height are presented in Table 6.29. The overall stature for females ranged from 144.50 cm to 163.25 cm, whilst males ranged between 150.03 cm and 174.43 cm (Fig. 6.31). No outliers were discovered within both the female and male data sets. As expected, a *t*-test with unequal variances determined that stature as estimated using the revised Fully anatomical method demonstrated statistically significant differences between females and males within this period ($p<0.01$) (sexual dimorphism=5.84). Vertebral column length tends to decrease with age due primarily to soft tissue alterations. Estimated stature was examined by age categories to ascertain if this fluctuation in the vertebral column would affect overall stature as approximately 30% of stature is derived from the vertebral column. With combined sexes, no statistically significant differences were discovered between individuals within the 18-25 year, 26-45 year, and 46+ year age categories (one-way ANOVA: $p=0.56$). However, due to significant differences between females and males with regard to stature, it was necessary to evaluate possible age related changes in stature within female and male categories separately. Unfortunately, only two females and one male under the age of 18 years had all skeletal elements (measured and estimated) necessary to estimate stature using the revised Fully anatomical method. Therefore, only females were evaluated.

Table 6.29: *Stature estimations of Romano-British females and males with all 29 skeletal elements present or estimated using the revised Fully Anatomical method from Raxter et al. 2006, and Raxter et al. 2007. Individuals aged within the 18-25 and 26-45 year age categories had stature estimated using the age corrected formula (1.009*Skeletal height-0.0426*mean age(21.5 or 35.5)+12.1). Individuals within the 46+ years and ADULT age categories were estimated using the non-age corrected formula (0.996*Skeletal height+11.7).*

		Estimated Adjacent Vertebrae	**Estimated Total Column from Thoracic and Lumbar Vertebrae**	**Estimated Total Column from Lumbar Vertebrae**	**Complete Skeleton for Fully Anatomical Estimation**	**Known and Estimated Vertebral Column Total**
Romano-British Females	N	2	4	16	18	40
	Min	144.40	154.08	147.95	148.06	144.50
	Max	163.25	158.22	156.43	161.66	163.25
	Mean	155.82	156.15	153.60	153.85	154.83
	SD	4.81	2.93	3.86	4.14	4.37
	SE	1.13	2.07	1.93	1.03	0.69
	One-way ANOVA test: p=0.6315					
Romano-British Males	N	4	2	13	17	36
	Min	166.13	156.44	151.58	150.03	150.03
	Max	171.08	160.06	174.28	174.43	174.43
	Mean	169.91	158.25	163.29	164.30	164.14
	SD	2.33	2.56	6.56	6.39	6.27
	SE	1.17	1.81	1.82	1.55	1.04
	One-way ANOVA test: p=0.1777					

Figure 6.31: *Estimated stature of Romano-British females and males using revised Fully Anatomical method and population specific regression equations for estimating vertebral column length.*

The mean estimated stature within each age category is presented in Fig. 6.32. Overall, stature sharply climbs between those <18 years and those over 18 years of age. A difference of 12.90 cm was calculated between the mean stature of <18 years and 18-25 year age categories and a 12.19 cm difference occurred between those <18 years and those 26-45 years. This disparity was statistically significant based on a one-way ANOVA (p=0.0014). A Tukey pairwise post-hoc test found significant differences between those <18 years and 18-25 years (p=0.0002) and those <18 years and 26-45 years (p=0.0003), whilst no differences were discovered between those within the 18-25 and 26-45 year age categories. This increase in stature between the youngest age category and older age categories could be caused by differential soft-tissue correction equations outlined in Raxter *et al.* (2007) or the fact that these individuals have yet to finish growing.

Within the male sample, the difference between the <18 year old male and all other age categories was much larger than within the female sample. Individuals with an age estimation of <18 years were separated from those 18-25 years as it was thought they had yet to finish growing, specifically within the torso. The greatest disparity materialized between <18 years and 18-25 year age categories with a 17.70 cm difference in mean estimated stature, closely followed by those within the 26-45 year age category with a 16.25 cm discrepancy. The large difference between those within the youngest age category (<18 years) and all other age categories likely indicates that whilst their long bones had fused, their trunk had yet to finish growing. Though there was a divide between age categories, no statistically significant differences between those within the 18-25 year, 26-45 year, and 46+ year age categories was evident based on a one-way ANOVA (p=0.6344).

Figure 6.32: *Mean stature (cm) of Romano-British females and males within each age category*

Estimated stature was also evaluated by site. No statistically significant differences were found between Roman London, the Roman Suburbs of Winchester (RSW), Butt Road, Poundbury, or Queensford Farm/Mill (QFM) (one-way ANOVA: p=0.3329). As with age categories, sites were divided into females and males (Fig. 6.33) and the mean estimated stature is presented in Table 6.30. No statistically significant differences were noted between sites. The females and males with the greatest mean estimated stature came from RSW, whilst females from QFM and males from Roman London had the lowest mean estimated stature. The largest division between females and males occurred at QFM with an 11.3 cm difference in mean estimated stature, though statistically this was not significant.

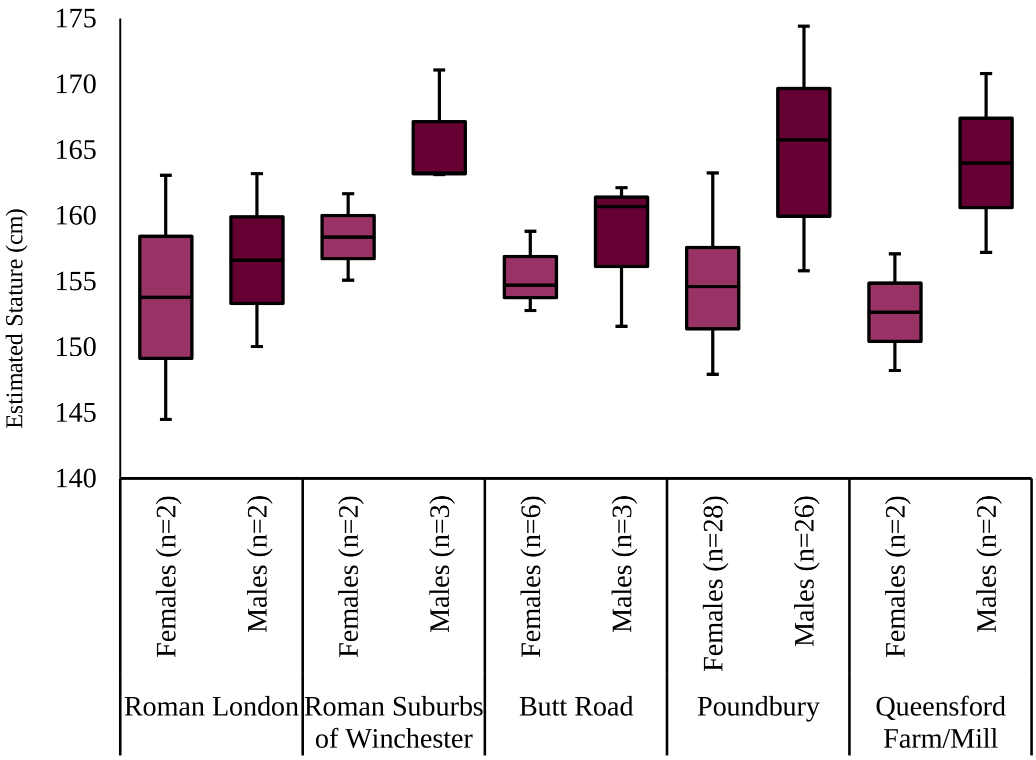


Figure 6.33: *Estimated stature (cm) of Romano-British females and males at each site analysed using the revised Fully anatomical method. "n"=number of individuals with stature estimated at each site*

Table 6.30: *Mean stature, standard deviation, and standard error for Romano-British females and males at each site.*

		Roman London	**RSW**	**Butt Road**	**Poundbury**	**QFM**
Romano-British Females	N	2	2	6	28	2
	Mean	153.8	158.4	155.2	154.7	152.7
	SD	13.1	4.7	2.1	4.1	6.3
	SE	9.3	3.3	0.9	0.8	4.4
	Welch F test for unequal variance: p=0.9326					
Romano-British Males	N	2	3	3	26	2
	Mean	156.6	165.8	158.1	165.2	164.0
	SD	9.3	4.6	5.7	5.8	9.6
	SE	6.6	2.6	3.3	1.1	6.8
	Kruskal-Wallis test: p=0.9010					

The only exception was between the female and male populations at Poundbury (*t*-test: *t*= -15.36, p<0.01) with a 10.5 cm difference in mean estimated stature. However, it must be stated that differences between females and males at the remaining four sites may not have been discovered as their sample sizes were much smaller than Poundbury.

Summary:

- Statistically significant differences between Romano-British females and males were discovered using the Fully anatomical method, with the mean female stature falling 9.13 cm short of the mean male stature
- Romano-British females and males aged <18 years demonstrated a significantly shorter stature at death than those in the 18-25 year and 26-45 year age categories. Females <18 years demonstrated a 12 cm deficit when compared to older categories, whilst males demonstrated a 17.7 cm deficit. This significant difference in stature in both the female and male samples is likely to be caused by a vertebral column that has not reached its final length at the time of death, as all long bone elements would have been fused.
- Though statistically significant differences were discovered in stature between the total sample of females and males, this difference was not echoed between each site. This might be caused by smaller sample sizes. The only site with a statistically significant difference in final stature between females and males was Poundbury.

6.4.1.4 Early Medieval stature estimation utilizing the revised Fully anatomical method

Fewer individuals with complete or measurable skeletal elements necessary for the revised Fully anatomical method were present within the Early Medieval sample. From a sample of 490 individuals only 12 (nine males and three females) had all 29 of the required skeletal elements. Once again, age-adjusted and non-age-adjusted Fully anatomical method formulae outlined by Raxter *et al.* (2006, 2007) were compared using paired *t*-test and Wilcoxon tests to determine if estimated stature was statistically different between the two formulae. No outliers were discovered within both the female and male data sets. Within the female sample, no statistically significant difference was noted between reconstructed stature utilizing age-adjusted and non-age-adjusted formulae (p=0.5); however, within the male sample, statistically significant differences occurred (p=0.03). The lack of difference seen in the female sample may be an artefact of such a small sample population (n=3).

The number of Early Medieval individuals added to the original 12 individuals with complete skeletal elements utilizing methods to estimate missing vertebral elements are presented in Table 6.31. Using these methods, a total of five females and six males were added to those individuals with complete skeletal elements, with no statistically significant differences in final stature between those individuals for whom skeletal elements were measured and those with estimated skeletal elements (see Table 6.31). Final estimated stature of females and males within the Early Medieval sample using the revised Fully anatomical method is presented in Figure 6.34. Early Medieval females demonstrated a smaller range in height with an 8.46 cm difference between the tallest (158.0 cm) and the shortest (149.5 cm) individuals, whilst males had an immense difference of 39.2 cm.

Table 6.31: *Stature estimation of Early Medieval females and males. All 29 skeletal elements measured or estimated were utilized to estimate stature using the revised Fully Anatomical method from Raxter et al. (2006, 2007). Individuals aged within the 18-25 and 26-45 year age categories had stature estimated using the age corrected formula (1.009*Skeletal height-0.0426*mean age(21.5 or 35.5)+12.1). Individuals within the 46+ years and ADULT age categories were estimated using the non-age corrected formula (0.996*Skeletal height+11.7).*

		Estimated Adjacent Vertebrae	**Estimated Total Column from Thoracic and Lumbar Vertebrae**	**Estimated Total Column from Lumbar Vertebrae**	**Complete Skeleton for Fully Anatomical Estimation**	**Known and Estimated Stature Total**
Early Medieval Females	N	1	1	3	3	8
	Min	156.7	149.5	151.5	154.8	149.5
	Max	156.7	149.5	157.2	158.0	158.0
	Mean	156.7	149.5	153.6	156.2	154.4
	SD	0	0	3.20	1.66	3.08
	SE	0	0	1.85	0.96	1.09
	Two sample *t*-test between complete and estimated column from lumbar vertebrae: p=0.28					
Early Medieval Males	N	1	1	4	9	15
	Min	173.81	164.55	149.56	155.65	149.56
	Max	173.81	164.55	165.02	188.78	188.78
	Mean	173.81	164.55	159.46	170.13	167.16
	SD	0	0	7.20	9.63	9.50
	SE	0	0	3.60	3.21	2.45
	Two sample *t*-test between complete and estimated column from lumbar vertebrae: p=0.08					

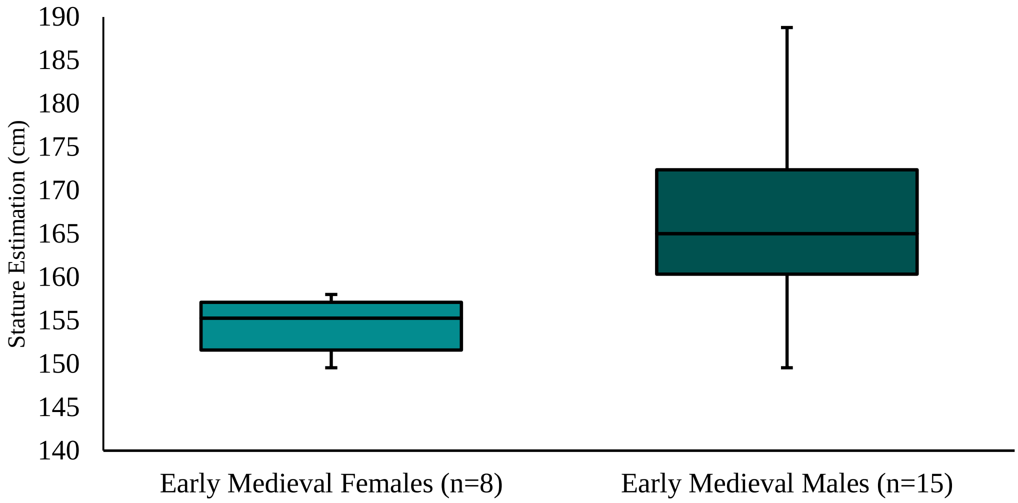


Figure 6.34: *Estimated stature of Early Medieval females and males using the revised Fully Anatomical method and population specific regression formulae estimating vertebral column length. "n"= number of individuals*

Differences in stature between females and males were assessed using a two-sample *t*-test with a statistically significant difference found between females and males (unequal t=-4.74; p=0.0001). The discrepancy between female and male mean stature was larger than the Romano-British sample with a higher degree of sexual dimorphism detected (sexual dimorphism=7.92). Unfortunately, due to small sample sizes within the female and male samples, differences in final stature between age categories could not be assessed, however Figure 6.35 displays the mean height of females and males within each age category. A slight decline in stature is demonstrated from the 26-45 year to 46+ year age categories for both sexes.

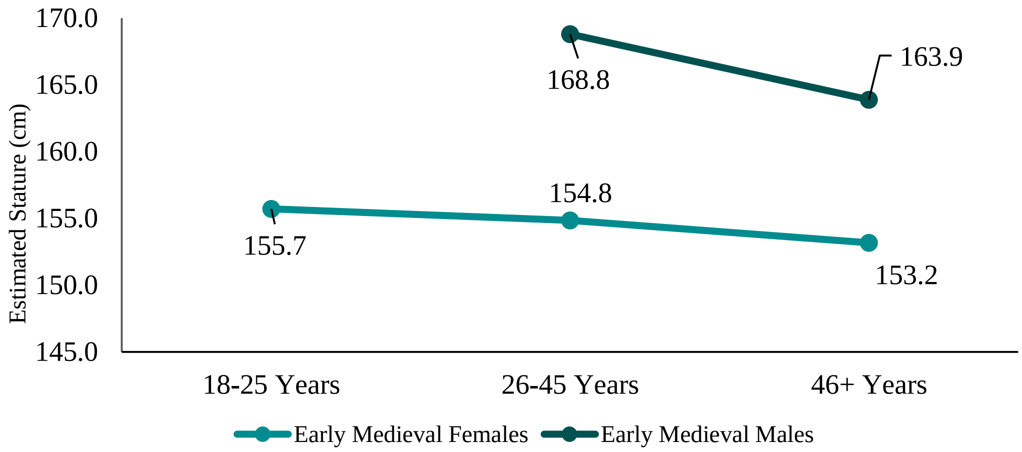


Figure 6.35: *Mean stature of Early Medieval females and males within each age category.*

To maintain consistency with the analysis of stature estimation between the two periods, stature estimation within the Early Medieval period was analysed by sites clustered into similar locations (regions) when possible. Table 6.32 presents the mean stature estimation of females and males within each region. The small female sample size did not allow for the statistical comparison of stature between regions. Males from the Eastern region were 8.02 cm shorter than the other three regions present, although this difference was not statistically significant (one-way ANOVA: p=0.33). The range in stature estimations for both the female and male samples can be found in Figure 6.36. The difference between female and male mean stature in the Oxfordshire region was 18.83 cm, in the Eastern region was 12.03 cm, and 9.91 cm at Apple Down. This large difference in mean stature within the Oxfordshire region could not be compared statistically.

Table 6.32: *Mean stature estimations of females and males within each region within the Early Medieval period. Two-sample t-test and a one-way ANOVA test were performed to assess potential differences between regions within each sex category. SD= Standard Deviation, SE= Standard Error*

		Oxford.	**Hamp.**	**Kent**	**Eastern**	**Castledyke**	**Apple Down**
Early Medieval Females	N	1	1	N/A	3	N/A	3
	Mean	154.76	155.79	N/A	150.99	N/A	157.31
	SD	0	0	N/A	1.28	N/A	0.67
	SE	0	0	N/A	0.74	N/A	0.39
	t-Test comparing Eastern and Apple Down: p=0.0016						
Early Medieval Males	N	3	N/A	1	6	N/A	5
	Mean	173.59	N/A	172.32	163.02	N/A	167.22
	SD	14.32	N/A	0	8.60	N/A	7.60
	SE	8.27	N/A	0	3.51	N/A	3.40
	One-way ANOVA test comparing Oxfordshire, Eastern, and Apple Down: p=0.3312						

Summary:

- Statistically significant differences were found in final stature calculated using the Fully anatomical method between females and males within the Early Medieval sample. This difference in stature is greater than the difference found between Romano-British females and males.
- Although few individuals were available to assess differences in final stature between age categories, slight declines in stature through ageing were noted.

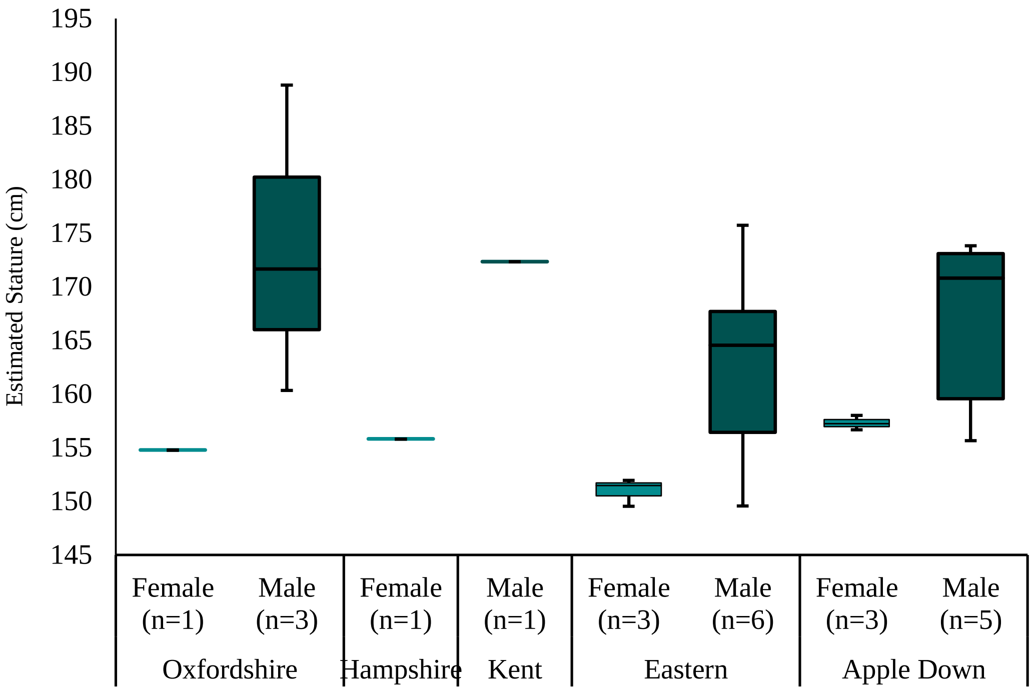


Figure 6.36: *Range in stature estimations (cm) for Early Medieval females and males within each region. Some regions only had one individual present and therefore have no maximum or minimum values. "n"=number of individuals within each region.*

6.4.1.5 Comparison of Romano-British and Early Medieval stature calculated from the revised Fully anatomical method

Based on previous studies' identification of increasing stature between the individuals inhabiting England between the Romano-British and Early Medieval periods, it was deemed crucial to analyse possible differences in stature estimated using the revised Fully anatomical method between the Romano-British and Early Medieval samples. The mean stature of females from the Romano-British and Early Medieval periods was 154.8 cm and 154.4 cm, respectively, which is statistically insignificant (two-sample *t*-test: t=0.24, p=0.81). For males, the mean stature of the Romano-British sample was 164.1 cm, whilst the mean stature of the Early Medieval sample was 167.2 cm. A two-sample *t*-test found no statistical significance between these two samples (t= -1.34, p=0.19) (Fig. 6.37). These results must be interpreted with caution as the sample size of those in the Early Medieval period were quite small in comparison to the Romano-British period.

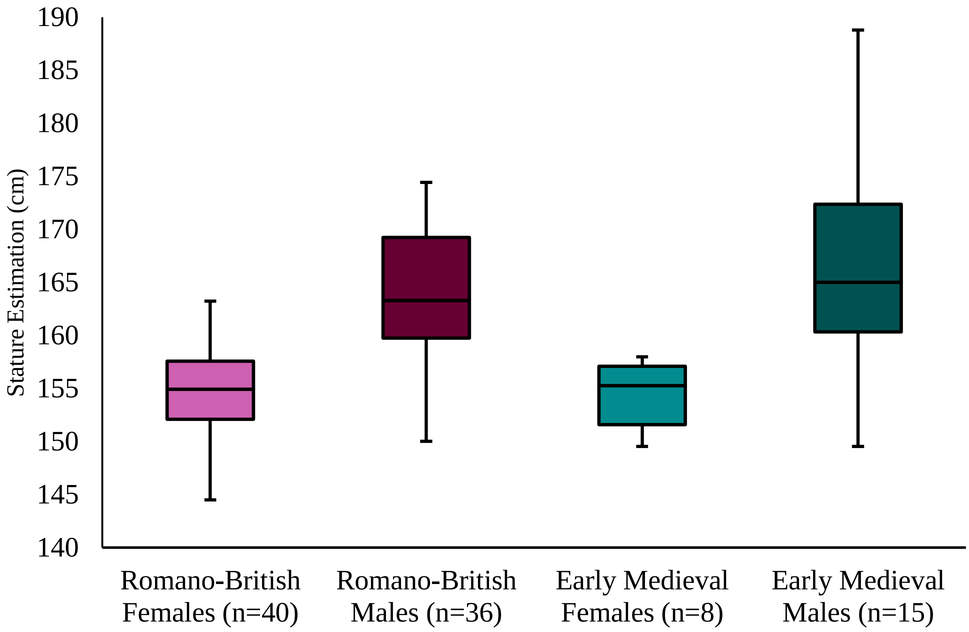


Figure 6.37: *Box and whiskers plots comparing the estimated statures using the revised Fully anatomical method of Romano-British and Early Medieval females and males. "n"=number of individuals*

To determine if any dramatic changes occurred between periods with regard to stature in each age category, females and males from each period were compared within the 18-25 year, 26-45 year, and 46+ year age categories (Fig. 6.38). When all four categories (Romano-British females and males, Early Medieval females and males) were assessed within each age category, statistically significant differences were noted, however these differences occurred between the sexes and not the periods. Overall, no changes were detected in final stature within each age category through time.

Finally, stature between periods were evaluated by sites and regions. Each Romano-British site was compared to Early Medieval regions. When each site and region were divided into female and male categories, statistically significant differences between Romano-British and Early Medieval females were discovered (One-way ANOVA: p=0.0013). Tukey's pairwise post-hoc test discovered the majority of these differences between females came from Kent females and Romano-British females from Poundbury (p=0.02) and QFM (p=0.04). The Early Medieval females from Apple Down were 2.6 cm taller than females at Poundbury. When males from all sites were compared between the two periods, statistically significant differences were found overall (Kruskal-Wallis: $p<0.0001$). Males from Early Medieval Oxfordshire were significantly taller than males from all Romano-British sites, excluding QFM (Bonferroni-corrected Mann-Whitney pairwise post-hoc tests: $p<0.002$), whilst males from Apple Down were significantly taller than males from all Romano-British sites (Bonferroni-corrected Mann-Whitney pairwise post-hoc tests: $p<0.0329$). Generally, males from RSW were significantly shorter than males from Early Medieval males in the Eastern region (Bonferroni-corrected Mann-Whitney pairwise post-hoc test: $p=0.0389$).

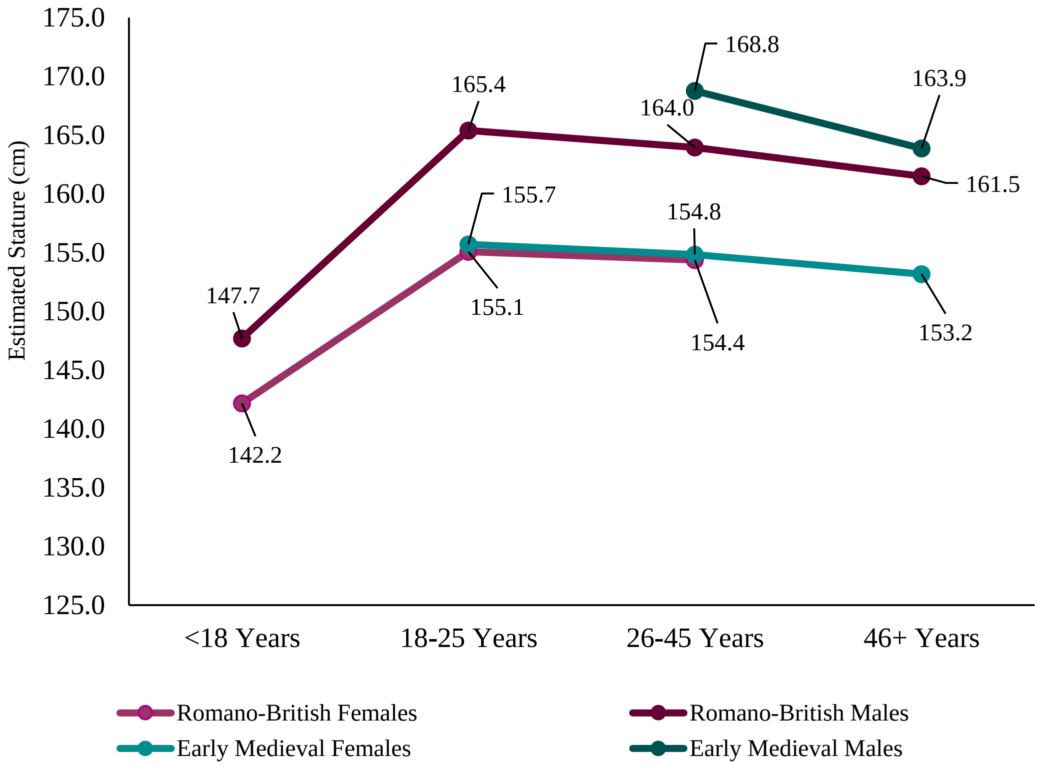


Figure 6.38: *Mean stature of Romano-British and Early Medieval females and males within each age category utilising the revised Fully anatomical method.*

Summary:

- Based on the limited sample size available for comparisons, no statistically significant differences amongst the Romano-British and Early Medieval females and the Romano-British and Early Medieval males were found.

- Diachronic changes in stature could not be assessed within female or male samples as the sample sizes were too small, however all four groups demonstrate a decrease in stature through age.
- When assessed by sex, statistically significant differences in estimated stature between Romano-British and Early Medieval females and males from several sites occurred. Males from Apple Down were significantly taller than Romano-British males. Females from Kent were significantly taller than females at Poundbury and QFM

6.4.2 Population specific mathematical regression formulae

One of the major aims of this thesis was to create population specific mathematical regression formulae to calculate stature for both the Romano-British and Early Medieval periods. Individuals who had their stature calculated using the revised Fully anatomical method (Raxter *et al.* 2006, 2007) (including those whose vertebral columns were estimated) were used to create stature formulae from major long bones. The aim was that these formulae would address the differences in body proportions between the Romano-British and Early Medieval samples, as well as between females and males within the same time period. For example, vertebral column length varies not just between females and males within the same period, but between the two periods. This variation has the potential to impact the accuracy of final stature estimates. The following sections will present the new mathematical regression formulae created specifically for the Romano-British and Early Medieval periods from stature calculated using the revised Fully anatomical method. It will also report adult stature using the newly generated equations and compare stature between females and males, age categories, and site/regional locations.

6.4.2.1 New mathematical regression formulae for the Romano-British sample

Mathematical regression equations were generated for all long bones, excluding the ulna and fibula as they were not included in this analysis. Previous analysis demonstrated the need for sex specific formulae, therefore formulae for females and males were calculated separately. The maximum number of females used to construct new regression formulae was 40 individuals, whilst for males it was 36 individuals. Fewer individuals were present with humeri and radii than femora and tibiae, as the latter are a prerequisite for using the Fully anatomical method and the former are not. Formulae were produced using ordinary least squares regressions. The independent variable was long bone length, with estimated stature as the dependent variable. Figures demonstrating these linear regression models can be found in Appendix 3 Figures 10-15. Table 6.33 presents the mathematical regression formulae created using the Fully anatomical method. Overall, the linear regression formula with the lowest standard error for both females and males utilized the sum of the maximum length of the femur and length of the tibia. The mean percent prediction error (mean PPE) and root-mean-square for each equation is presented in Table 6.34. Vercellotti *et al*.'s (2009) formula was used to calculate mean PPE:

$$PPE = \frac{regression\ stature - anatomical\ stature}{anatomical\ stature} \times 100$$

The mathematical regression formula with the lowest mean PPE was the sum of the maximum femur and tibia for both females and males.

In total, stature was estimated for 682 Romano-British individuals (293 females and 389 males) using the formulae from femora, tibiae, humeri, or radii. For those individuals with multiple long bones present, the skeletal element with the lowest standard error associated with the mathematical regression formula was used to calculate stature at death. The results are presented in Table 6.35. There was no statistically significant difference between the mean statures calculated from each long bone element. These stature calculations come from different individuals depending on bone survival. Priority was given to the summed lower limb length if most other long bones were present. When the estimated stature from all 293 females and 389 males were compared, statistically significant differences between the sexes occurred ($p<0.0001$). These differences were found within stature calculated using the maximum femur and tibia ($p<0.0001$), the maximum femur ($p<0.0001$), the tibia ($p<0.0001$), the humerus ($p<0.0001$), and the radius ($p<0.0001$). Males tend to have a greater range in stature values than females. The maximum and minimum stature of females and males along with the standard error associated with each regression equation is found in Figure 6.39.

Table 6.33: *Linear regression formulae calculating Romano-British stature at death. [1]Femur$_b$ represent bicondylar or physiological length of the femur. [2]Femur$_m$ represents the maximum length of the femur.*

	Skeletal Element	**N**	**Equations**	***r***	**SEE (mm) (%SEE)**	**Mean Difference**	**95% CI** Lower	Upper	**Standard Deviation**	**Standard Error**
Romano-British Females	Femur$_m$ + Tibia	40	1.2122 (Fem$_m$ + Tib) + 64.576	0.87	2.19 (1.41%)	1.32*10-3	0.67	0.67	2.16	0.34
	Femur$_m$[2]	40	2.1210 (Fem$_m$) + 67.052	0.85	2.30 (1.49%)	-1.71*10-3	0.71	0.70	2.27	0.36
	Femur$_b$[1]	40	2.1152 (Fem$_b$) + 68.185	0.85	2.34 (1.51%)	2.39*10-4	0.72	0.72	2.31	0.37
	Tibia	40	2.4228 (Tib) + 74.806	0.81	2.57 (1.66%)	-9.71*10-4	0.79	0.79	2.54	0.40
	Humerus	35	2.5529 (Hum) + 79.566	0.68	3.17 (2.05%)	8.88*10-3	1.04	1.03	3.12	0.53
	Radius	35	2.3363 (Rad) + 104.01	0.62	3.65 (2.36%)	-0.1030	1.22	1.01	3.37	0.57
Romano-British Males	Femur$_m$ + Tibia	36	1.3356 (Fem$_m$ + Tib) + 57.377	0.92	2.46 (1.50%)	-3.29*10-3	0.80	0.79	2.43	0.41
	Femur$_b$[1]	36	2.296 (Fem$_b$) + 62.654	0.92	2.47 (1.51%)	-0.0172	0.81	0.78	2.44	0.41
	Femur$_m$[2]	36	2.2819 (Fem$_m$) + 62.478	0.92	2.47 (1.51%)	-1.83*10-3	0.80	0.79	2.44	0.41
	Tibia	36	2.9624 (Tib) + 59.322	0.88	2.96 (1.81%)	8.84*10-4	0.95	0.95	2.92	0.49
	Radius	31	3.758 (Rad) + 73.176	0.81	3.60 (2.20%)	6.65*10-3	1.24	1.25	3.54	0.63
	Humerus	32	2.8677 (Hum) + 71.776	0.80	3.81 (2.33%)	-2.10*10-5	1.30	1.30	3.75	0.66

Table 6.34: *Mean percent prediction error and Root-Mean-Square (%) for each Romano-British formula created using ordinary least squares linear regression.*

Long Bone Measurement	**Mean Percent Prediction Error**		**Root Mean Square Error (%)**	
	Male	Female	Male	Female
Femur (Physiological)	0.06	0.03	0.16	0.01
Femur (Maximum)	0.06	0.04	0.03	0.12
Tibia (Maximum)	0.07	0.04	0.15	0.15
Femur and Tibia	0.03	0.02	0.35	0.24
Humerus	0.13	0.24	0.17	0.30
Radius	0.08	0.06	0.07	0.38

Table 6.35: *Summary statistics for the stature of Romano-British females and males. SD=Standard Deviation, SE=Standard Error of the Estimate*

		Fully Anatomical Method	**$Femur_m$ + Tibia**	**$Femur_m$**	**Tibia**	**Humerus**	**Radius**
Romano-British Females	N	40	134	58	27	26	8
	Min	144.50	145.67	146.80	145.07	146.20	150.74
	Max	163.25	166.04	162.71	162.27	162.02	156.58
	Mean	154.83	154.95	154.24	154.86	153.63	153.25
	SD	4.37	4.28	3.56	4.22	4.22	1.88
	SE		±2.19	±2.30	±2.57	±3.17	±3.65
	One-way ANOVA test: p=0.4230						
Romano-British Males	N	36	177	80	50	36	10
	Min	150.03	146.73	151.24	155.23	154.65	155.85
	Max	174.43	179.85	174.75	181.67	175.59	170.88
	Mean	164.14	164.44	163.03	167.62	164.96	164.16
	SD	6.27	6.17	5.76	6.69	4.75	5.05
	SE		±2.46	±2.47	±2.96	±3.81	±3.60
	Welch F test: p=0.1380						

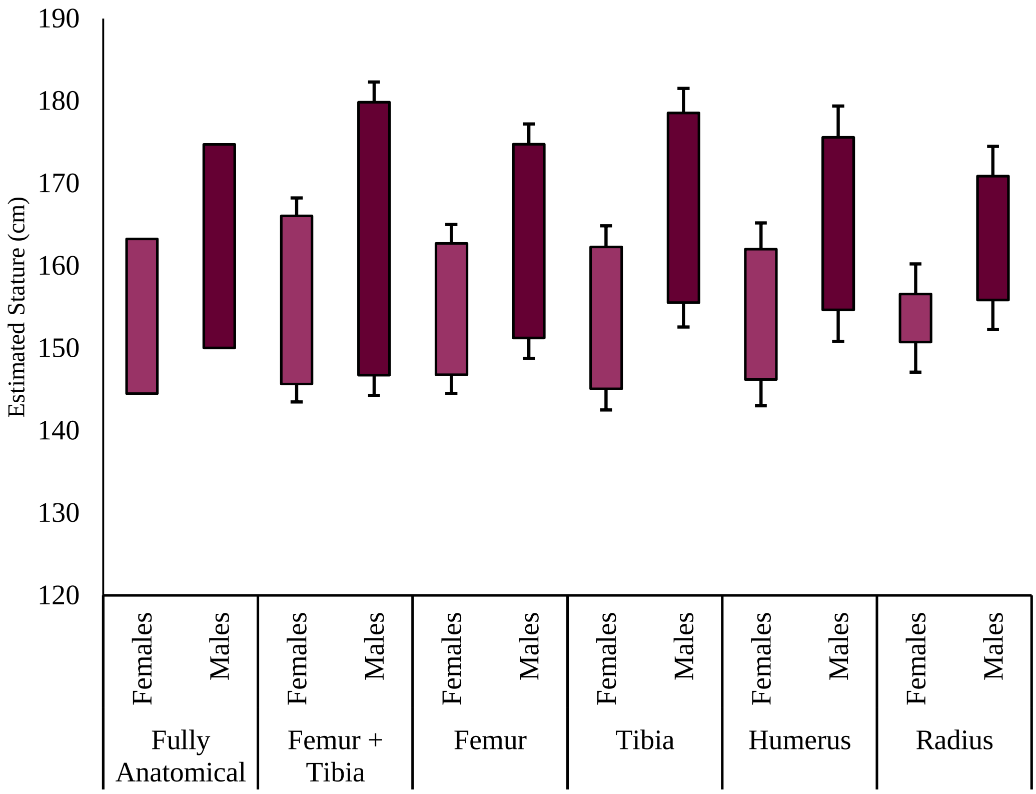


Figure 6.39: *Stature estimation of Romano-British females and males from Fully Anatomical method and each mathematical regression formula. Fully anatomical stature does not have any error bars as it was taken as a 'known' stature.*

Stature was also assessed by age categories to determine if any statistically or biologically significant differences occurred through ageing. Age categories were assessed for individuals who had both the maximum femur and tibia present as well as those calculated using the Fully anatomical method. Stature estimates that were outliers were removed from the sample. Outliers of the sample were greater than 1.5 times the interquartile range from the median. Mean stature for each age category is found in Figure 6.40. All age categories were compared within the female and male samples. A significant difference was found within the female sample (one-way ANOVA: $p<0.0010$) with a Tukey post-hoc test demonstrating a significant difference in stature in the 26-45 year and 46+ year age categories with the latter 4.37 cm shorter than the former. No statistically significant differences were present within the male sample (one-way ANOVA: $p=0.57$).

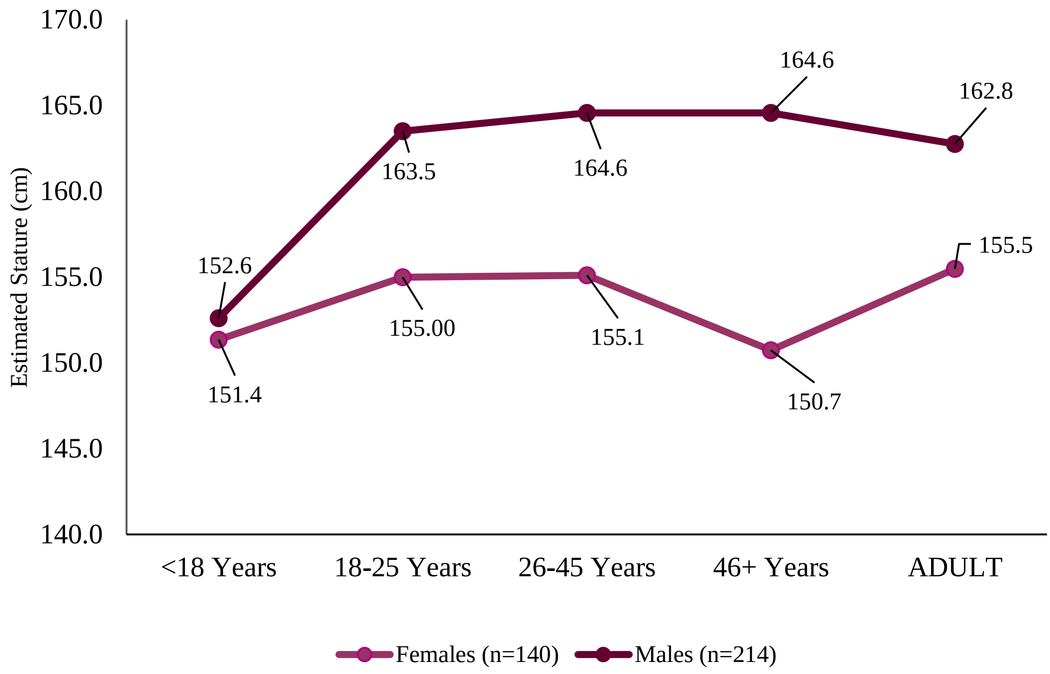


Figure 6.40: *Mean stature for Romano-British females and males within each age-at-death category calculated using the revised Fully anatomical method and summed maximum femur and tibia equation.*

Finally, Romano-British stature was assessed between sites (Fig. 6.41). Similar to the assessment between age categories, sites were examined with statures calculated using either the Fully anatomical method or the regression equation based on the sum of the maximum femur and tibia. Two females and one male were removed from the sample as they were outliers. Based on one-way ANOVA analyses, no statistically significant differences were found between females from all sites (p=0.10) and males from all sites (p=0.15). Summary statistics for final stature of females and males from all sites using the Fully anatomical method, as well as mathematical regression equations using the summed length of the femur and tibia and the maximum length of the femur can be found in Table 6.36. The degree of sexual dimorphism in stature within each site was calculated and is presented in Table 6.37.

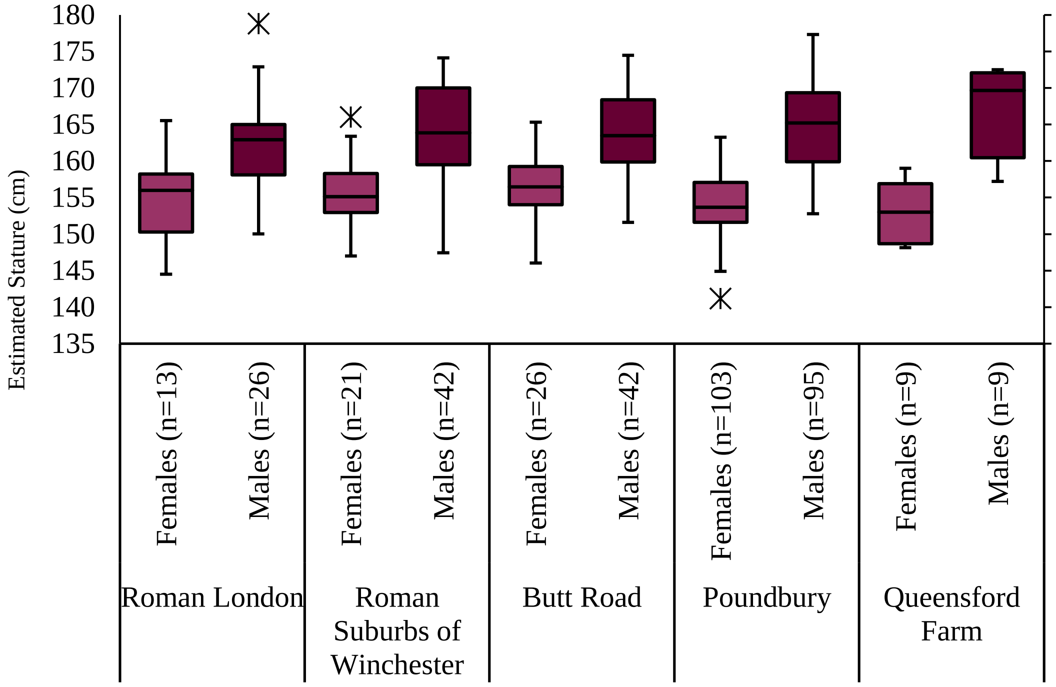


Figure 6.41: *Box and whiskers plots for estimated stature for Romano-British females and males at each site using the revised Fully anatomical method and population specific mathematical regression formula for the summed femur and tibial lengths. Black asterisk represent outliers within each site.*

Table 6.36: *Summary statistics for the stature of Romano-British females and males from all five sites using Fully anatomical calculations and population specific formulae using the summed lower limb length (femur and tibia). SE=standard error, CoV=coefficient of variation*

		Roman London	**RSW**	**Butt Road**	**Poundbury**	**QFM**
Romano-British Females	***N***	13	21	26	103	9
	Max	165.53	163.37	165.31	163.25	159.01
	Min	144.50	147.01	148.81	144.88	148.12
	Average	155.16	155.40	156.62	154.19	153.67
	Standard Dev.	5.80	4.38	3.94	3.88	4.22
	SE	1.61	0.96	0.77	0.38	1.41
	Variance	33.67	19.22	15.49	15.09	17.84
	CoV	3.74	2.82	2.51	2.52	2.75
	One-way ANOVA: p=0.0881					
Romano-British Males	***N***	26	42	42	95	9
	Max	172.88	174.11	174.48	177.33	172.50
	Min	150.03	147.44	151.58	152.80	157.21
	Average	161.88	164.56	163.80	164.71	166.56
	Standard Dev.	5.22	5.94	5.34	5.88	6.22
	SE	1.02	0.92	0.82	0.60	2.07
	Variance	27.25	35.34	28.52	34.59	38.65
	CoV	3.23	3.61	3.26	3.57	3.73
	One-way ANOVA: p=0.1452					

Table 6.37: Two-sample t-test comparing stature of Romano-British females and males at each site analysed. Sexual dimorphism calculated using formula seen in Section 5.7 Chapter Five. Bonferroni-corrected α=0.0100.

	Roman London	RSW	Butt Road	Poundbury	QFM
Two-sample *t*-test	p=0.0015	p=0.0001	p=0.0001	p=0.0001	p=0.0004
Sexual Dimorphism	4.24	5.73	4.49	6.60	8.05

Summary:

- Regardless of long bone regression equation utilized, statistically significant differences in final stature are seen in the total female and male samples. This difference in stature between females and males is also seen within all five sites analysed, each displaying high values of sexual dimorphism.
- When stature between sites within female and male samples were compared, no statistically significant differences arose.

6.4.2.2 New mathematical regression formulae for Early Medieval sample

Population specific mathematical regression formulae were also created for the Early Medieval samples using skeletal elements most frequently discovered in archaeological contexts. Sex specific formulae were created from females and males for whom stature was estimated using the Fully anatomical method (Table 6.38). In total, only eight females and 15 males were available for these equations. Ordinary least squares linear regressions were used to construct these formulae. Illustrations of these linear regressions are located in Appendix 3 Figures 16-21. The equations with the smallest standard error for both females and males were the sum of the maximum femur and tibia. The mean percent prediction error (formula presented in Section 6.4.2.1) and root-mean-square for each regression formula is listed in Table 6.39. These equations were deemed to be a reliable way to estimate stature of Early Medieval individuals using long bone lengths.

Table 6.38: *Mathematical regression formulae created using ordinary least squares for the Early Medieval population. [1]Femur$_m$ is the maximum length of the femur. [2]Femur$_b$ is the bicondylar or physiological length of the femur.*

	Skeletal Element	**N**	**Equations**	***r***	**SEE (%SEE)**	**Mean Difference**	**95% CI**		**Standard Deviation**	**Standard Error**
							Lower	Upper		
Early Medieval Females	Femur$_m$ + Tibia	8	1.2726(Fem$_m$ + Tib) +57.846	0.90	1.48 (0.96%)	-0.0024	0.94	0.93	1.35	0.48
	Tibia	8	2.0486(Tib) + 85.087	0.82	1.92 (1.24%)	0.0013	0.61	0.61	0.88	0.63
	Humerus	7	2.4134(Hum) + 81.331	0.81	2.04 (1.32%)	0.0004	1.40	1.40	1.86	0.70
	Femur$_b$[1]	8	1.7571(Fem$_b$) + 81.117	0.72	2.30 (1.49%)	0.0012	1.62	1.63	2.35	0.75
	Femur$_m$[2]	8	1.6672(Fem$_m$) + 84.334	0.71	2.33 (1.51%)	-0.0015	1.72	1.72	2.48	0.76
	Radius	5	2.8434(Rad) + 91.178	0.84	2.40 (1.55%)	-0.0012	1.82	1.82	2.08	0.93
Early Medieval Males	Femur$_m$ + Tibia	15	1.4938(Fem$_m$ + Tib) + 44.48	0.96	2.68 (1.61%)	0.0035	1.31	1.31	4.95	1.37
	Femur$_b$	15	2.7525(Fem$_b$) + 43.763	0.96	2.78 (1.66%)	0.0003	1.35	1.35	2.68	0.69
	Femur$_m$	15	2.7123(Fem$_m$) + 44.542	0.95	2.96 (1.77%)	-0.0012	1.44	1.44	2.85	0.74
	Tibia	15	3.1149(Tib) + 52.154	0.94	3.33 (1.99%)	-0.0012	1.62	1.62	3.21	0.83
	Radius	13	4.973(Rad) + 45.276	0.83	4.86 (2.87%)	0.0010	2.48	2.48	4.57	1.27
	Humerus	13	3.7392(Hum) + 43.998	0.80	5.17 (3.06%)	0.0004	2.69	2.69	4.95	1.37

Table 6.39: *Mean percent prediction error and root-mean-square error (%) of each regression formula. Formula used to calculate mean PPE from Vercellotti et al. 2009.*

Long Bone Measurement	**Mean Percent Prediction Error**		**Root-Mean-Square Error (%)**	
	Male	**Female**	**Male**	**Female**
Femur (Physiological)	0.025	0.017	0.03	0.12
Femur (Maximum)	0.0267	0.0161	0.12	0.15
Tibia (Maximum)	0.036	0.013	0.12	0.13
Femur and Tibia	0.026	0.005	0.35	0.24
Humerus	0.082	0.013	0.04	0.04
Radius	0.073	0.014	0.10	0.12

Summary statistics for the estimated stature of females and males from each equation are presented in Table 6.40. Estimated stature was assessed for potential differences between females and males with the outliers removed. First, stature estimated from the same skeletal elements were tested to determine if significant differences occurred between females and males. Statistically significant differences in estimated stature occurred with the humerus (*t*-test: t= -4.19, p<0.0001), with the radius (*t*-test: *t*= -7.73, p<0.0001), with the maximum femur (*t*-test unequal variance: *t*= -13.75, p<0.0001), the tibia (*t*-test: *t*= -7.20, p<0.0001), and finally between the sum of maximum femur and tibia (*t*-test unequal variance: *t*= -16.28, p<0.0001) (Bonferroni-corrected α=0.0100). Significant differences occurred regardless of which long bone was used to calculate stature and the differences between the mean stature for females and males in each equation was larger than the standard error associated with the equation (Fig. 6.42). The mean difference between the mean stature of females and males was 12.02 cm.

Table 6.40: *Summary statistics of estimated stature of Early Medieval females and males using newly created mathematical regression formulae from individuals with stature calculated using the Fully anatomical method. SD=Standard Deviation, SE=Standard Error of the Estimate*

		Fully Anatomical Method	**Femur$_m$ + Tibia**	**Femur$_m$**	**Tibia**	**Humerus**	**Radius**
Early Medieval Females	N	8	87	15	32	26	8
	Min	149.54	146.04	151.19	146.14	151.56	152.03
	Max	158.06	169.96	158.52	171.33	164.59	162.83
	Mean	154.43	156.32	155.41	156.83	157.61	157.71
	SD	3.08	5.16	3.92	5.15	3.78	3.67
	SE		±1.48	±2.33	±1.92	±2.04	±2.40
	Welch F test: p=0.1115						
Early Medieval Males	N	15	96	44	24	9	11
	Min	149.56	153.38	153.03	152.14	157.67	165.13
	Max	188.78	186.54	182.60	178.62	176.37	173.58
	Mean	167.16	170.99	170.29	167.88	165.10	169.01
	SD	9.50	6.97	6.33	6.32	6.17	2.72
	SE		±2.68	±2.96	±3.33	±5.17	±4.86
	Welch F test: p=0.0722						

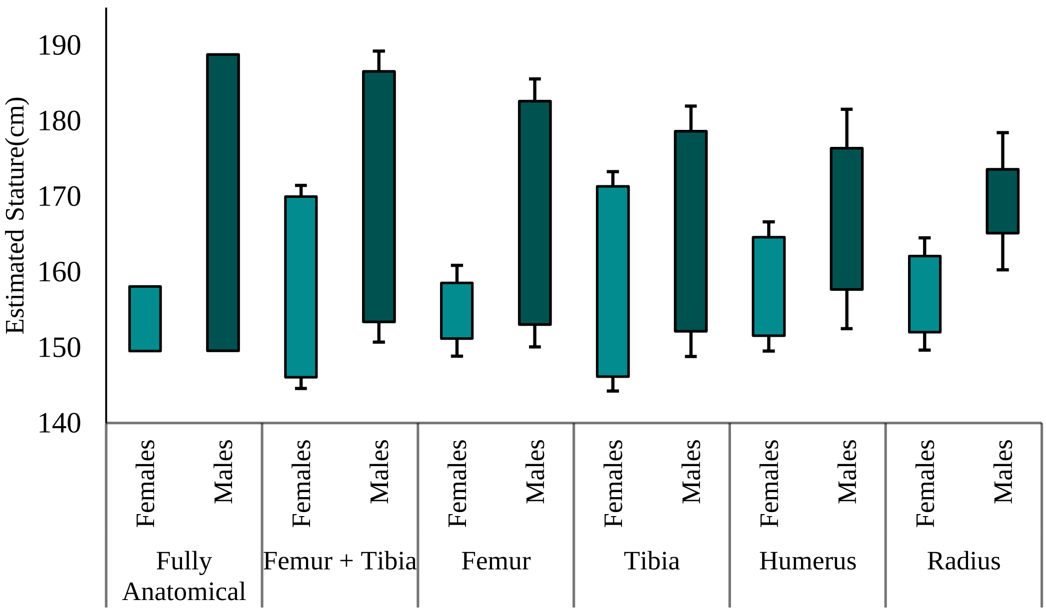


Figure 6.42: *Stature estimation of Early Medieval females and males from the revised Fully anatomical method and each mathematical regression formula.*

Differences in stature were also examined within age categories as age-related differences were detected in the spinal column, which comprises a significant portion of final stature. Figure 6.43 illustrates the mean stature of females and males within each age category as calculated using either the Fully anatomical method or the regression formulae from the summed maximum femur and tibia with no statistically significant differences detected (Welch F test: p=0.18-females; one-way ANOVA: p=0.43-males).

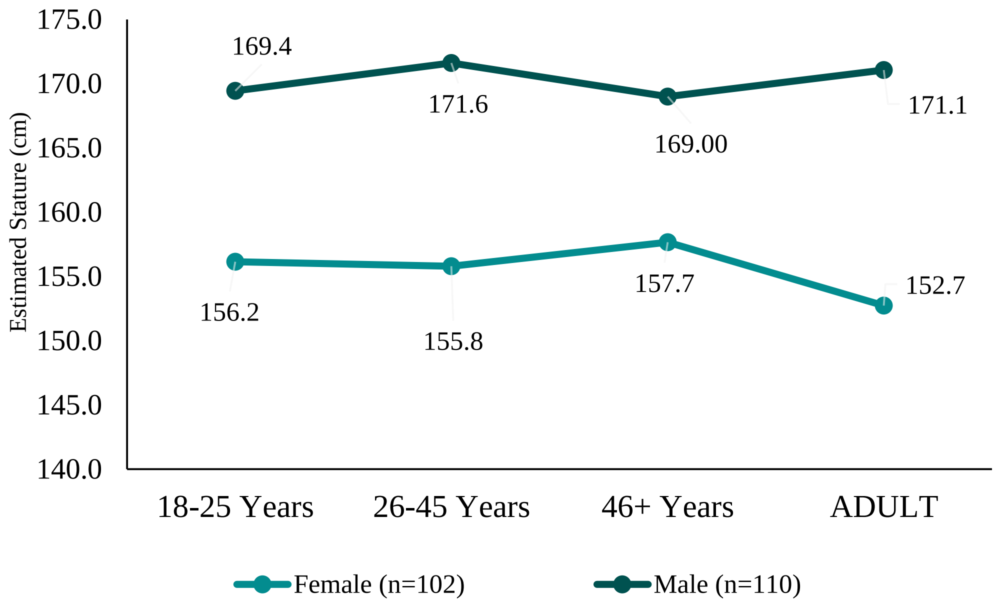


Figure 6.43: *Mean stature of Early Medieval females and males within each age-at-death categories*

Finally, estimated stature using the Fully anatomical method and the summed maximum femur and tibia regression equations were used to assess possible differences between Early Medieval sites from different geographical regions (Table 6.41). Figure 6.44 displays box and whisker plots of stature estimations within each region for females and males. No statistically significant difference was found within the female sample based on a one-way ANOVA (p=0.22). Similar to females in this period, no statistically significant differences between all six regions was found in the male sample (one-way ANOVA: p=0.22). Two-sample *t*-tests were also used to detect differences in stature between females and males within each regions (Table 6.42). The difference in mean estimated stature ranged from 12.01 cm within the Kent region to 18.87 cm within Apple Down. All these values were outside the standard error associated with the regression equations and were therefore considered to not only to be statistically significant, but biologically different.

Table 6.41: *Summary statistics for Early Medieval stature calculated using the Fully anatomical method and the population specific formulae using the summed lower limb length at sites within regions. Oxford.=Oxfordshire, Hamp.=Hampshire, Castle.=Castledyke*

		Oxford.	**Hamp.**	**Kent**	**Eastern**	**Castle.**	**Apple Down**
Early Medieval Females	***N***	15	18	8	25	9	19
	Ave	156.45	156.99	158.84	154.78	157.00	154.69
	St Dv	5.04	4.55	6.12	5.21	3.72	4.05
	SE	1.30	1.07	2.16	1.04	1.24	0.93
	One-way ANOVA: p=0.223						
Early Medieval Males	***N***	20	19	6	36	11	18
	Ave	172.22	170.60	170.85	168.61	169.43	173.56
	St Dv	7.98	8.43	4.69	7.14	5.08	6.58
	SE	1.78	1.93	1.91	1.19	1.53	1.55
	One-way ANOVA: p=0.222						

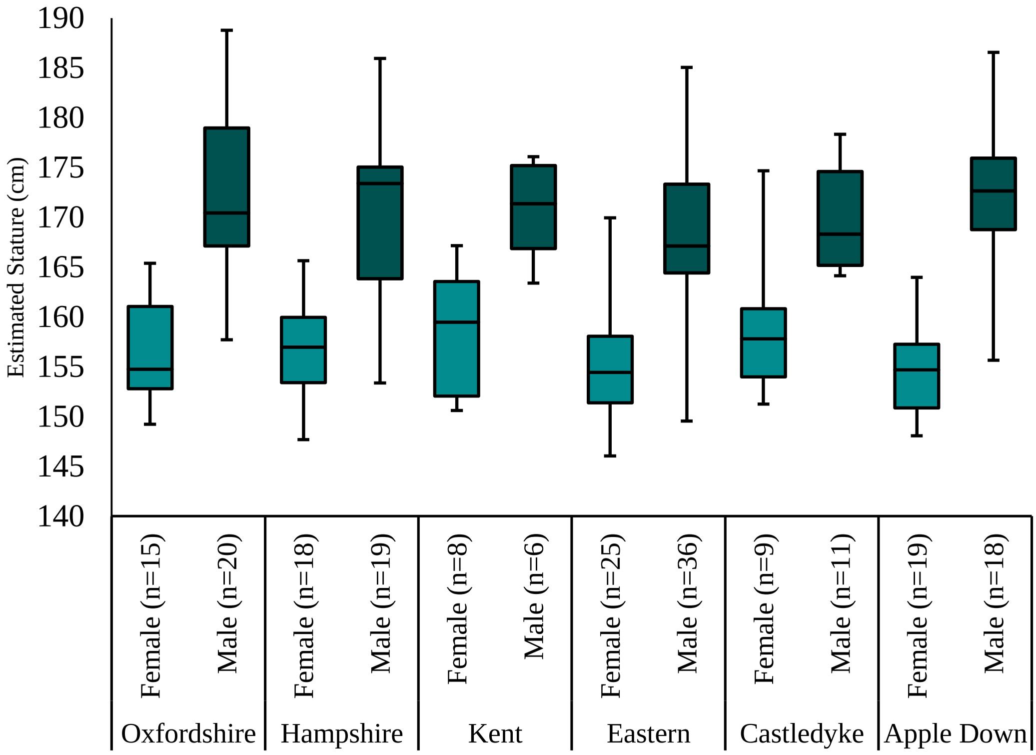


Figure 6.44: *Box and whiskers plots of estimated stature of Early Medieval female and males within each region*

Table 6.42: *Two-sample t-test comparing stature of Early Medieval females and males at each site analysed. Sexual dimorphism calculated using formula seen in Section 5.7 Chapter Five. Bonferroni-corrected α=0.0100.*

	Oxford.	**Hamp.**	**Kent**	**Eastern**	**Castledyke**	**Apple Down**
Two-sample *t*-test	t= -6.70 p<0.0001	t= -6.06 p<0.0001	t= -3.99 p=0.0030	t= -7.08 p<0.0001	t= -4.17 p=0.0008	t= -9.08 p<0.0001
Sexual Dimorphism	9.60	8.34	7.29	8.55	7.62	11.50

Summary:

- Statistically significant differences in final stature occurred between females and males within the Early Medieval sample, regardless of linear regression formulae used, age categories, or regional sites
- When all cemeteries within geographically close regions were compared, no statistically significant difference in final stature was observed.
- Sites within each region displayed larger degrees of sexual dimorphism, especially between females and males discovered at Apple Down.

6.4.2.3 Comparison of Romano-British and Early Medieval estimated stature

Interest in the transition between the Romano-British and Early Medieval periods prompted the analysis of stature within the female and male samples of each period. Stature was calculated using the Fully anatomical method when possible, or the use of the population specific regression formulae outlined above (sections 6.4.2.1 and 6.4.2.2) from the sum of the maximum femur and tibia lengths. Outliers within the female and male samples of each period were removed prior to statistical analysis. As stated previously, outliers were individuals whose stature fell above or below 1.5 times the interquartile range from the median. Stature was compared between these two periods within the female and male categories, as well as between age categories and archaeological sites and regions.

Summary statistics are presented in Table 6.43. Females from the Romano-British and Early Medieval period demonstrated differences in stature that were statistically significant (*t*-test unequal variance: p=0.02). Although stature between these two groups may be statistically different, the difference between mean statures was only 1.37 cm. This difference was less than the standard error associated with the Romano-British calculation using the sum of the maximum femur and tibia length (±2.19 cm) and the Early Medieval standard error (±1.48 cm). Therefore, statistically, Romano-British and Early Medieval females were different with regard to final stature, however, when standard error associated with each regression equation was included, this significance was not so great.

Table 6.43: *Summary statistics of final stature within each sample based on sex estimation.*

	Romano-British Females	**Early Medieval Females**	**Romano-British Males**	**Early Medieval Males**
N	214	95	213	111
Min	144.50	146.04	148.15	152.03
Max	166.04	169.96	178.81	188.78
Mean	154.79	156.16	164.27	170.49
SD	4.21	5.04	5.81	7.37
SE	±2.19	±1.48	±3.27	±2.68

For males, a statistically significant difference in stature was present between the Romano-British and Early Medieval periods ($p<0.01$). The difference between the mean statures in males was 6.22 cm, which was greater than the standard error associated with using the regression formula. The difference between the shortest and tallest individuals within each sample were greater within the Early Medieval than Romano-British males (36.75 cm and 30.66 cm, respectively), whilst the female sample was fairly equal within both the Romano-British and Early Medieval periods (21.46 cm and 23.92 cm, respectively).

To examine the diversity between the Romano-British and Early Medieval sites within similar locations, stature estimations within the female and male samples were compared to one another (Fig. 6.45) and tested using a one-way ANOVA.

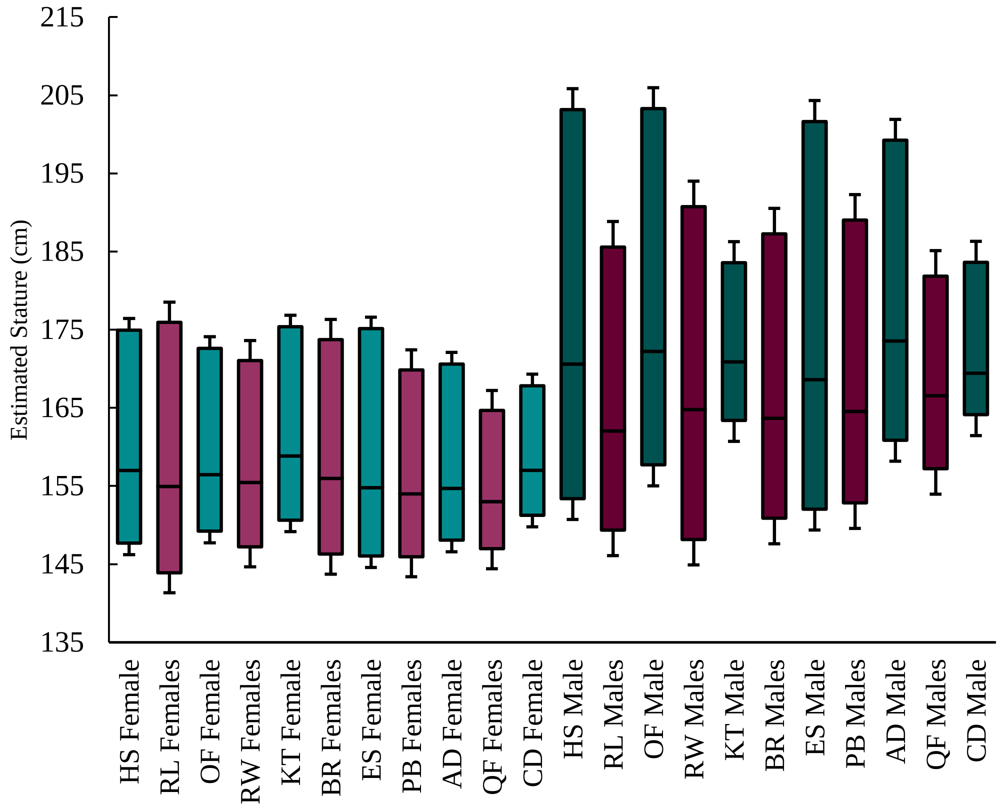


Figure 6.45: *Comparison of estimated stature between Romano-British sites and Early Medieval regions for females and males. HS=Hampshire, RL=Roman London, OF=Oxfordshire, RW= Roman Suburbs of Winchester, KT=Kent ,BR=Butt Road, ES=Eastern, PB=Poundbury, AD=Apple Down, QF=Queensford Farm/Mill, CD=Castledyke*

In the female sample, statistically significant differences in final stature occurred (one-way ANOVA: $p<0.01$). Tukey pairwise post-hoc tests found these differences to occur between QFM and the Early Medieval sites in Oxfordshire ($p=0.03$), Hampshire ($p=0.01$), and Kent ($p<0.01$); between Poundbury and Hampshire ($p=0.04$) and Kent ($p<0.01$); and finally between Roman London and Kent ($p<0.01$). Interestingly, the shorter stature found at Poundbury was more closely related to the female stature in Early Medieval sites in eastern England and Apple Down. Similar to females from Poundbury, those from Queensford Farm/Mill were closest to the Eastern and Apple Down regions.

Stature found within the female samples from both periods contrast with the large range in stature seen within the male samples. Statistically significant differences were revealed between the Romano-British and Early Medieval sites (Welch F test for unequal variance: $p<0.01$). These differences occurred between all Romano-British sites and Oxfordshire and Apple Down (Games-Howell post-hoc: $p<0.01$). The shorter stature of males within Roman London also saw significant differences with all Early Medieval sites (Games-Howell post-hoc: $p<0.01$).

Summary:

- Despite being statistically different in stature, females from both periods had final statures that were within the standard error of the regression equations.
- The large difference in mean stature of males between periods led to statistically significant differences. Differences between mean stature in Romano-British sites and sites within the Early Medieval period were greater than the standard error associated with the regression formulae. Even when standard error is accounted for, stature of males from these periods remain quite different, with males from the Early Medieval period displaying higher mean stature.
- Females from QFM and Poundbury were statistically shorter than females from the sites located within Hampshire and Kent, who were amongst the tallest within the Early Medieval period sample.
- All Early Medieval sites were statistically different from four Romano-British sites within similar locations (Roman London, RSW, Butt Road, and Poundbury) with regard to final stature. Males from the Romano-British period tend to be shorter than males from the Early Medieval period. Although males from QFM demonstrated the greatest mean stature from the Romano-British period, it was statistically shorter than the mean male stature found at Apple Down, Oxfordshire, and Eastern sites.

6.4.3 Statistical comparison of published stature formulae and population specific regression formulae

A secondary aim of this thesis was to compare frequently cited formulae used to calculate stature for both Romano-British and Early Medieval populations to stature calculated using the revised Fully anatomical method. Many of the currently published regression formulae for estimating stature from long bones were created using modern reference samples from various geographic locations. For example, the reference sample for the mathematical regression formulae developed by Trotter and Gleser (1952) came from the Terry Skeletal collection, which is comprised of white and black American cadavers along with American World War II casualties. Olivier and Tissier (1975), utilised Rollet's data from individuals living in France in the late 19th and early 20th centuries. A comparison of the stature obtained using these regression formulae with that from the revised Fully anatomical method was undertaken to determine which formulae, if any, were most appropriate to the Romano-British and Early Medieval samples with respect to body proportion. Only formulae using the maximum femoral length, tibial length, and summed maximum femoral and tibial length were utilized as these skeletal elements had lower standard errors.

6.4.3.1 Romano-British Females

Ten linear regression formulae (maximum femoral length, tibial length, and summed maximum femoral and tibial length) were applied to the 40 Romano-British females for whom stature had been calculated using the revised Fully anatomical method. Summary statistics of estimated stature from each regression equation and results of the paired *t*-tests comparing 'known' stature (i.e. revised Fully anatomical method) and estimated stature can be found in Table 6.44. To prevent Type I errors a Bonferroni-correction was utilised to adjust the alpha level for significance. A total of 25 familywise tests were grouped together, lowering the alpha level to 0.0020.

Stature calculated using the maximum femoral length of Romano-British females' demonstrated highly variable estimated stature between equations (Fig. 6.46). From the ten formulae used to estimate stature, seven overestimated stature whilst three underestimated final stature. When compared to the 'known' stature, five formulae (Trotter and Gleser (1952/1958) 'white' formulae, Trotter (1970), Dupertuis and Hadden (1951), Bach (1965), Hauser *et al*. (2005), and Černy and Komenda (1982)) produced significantly different results using a paired *t*-test. Three of these formulae (Dupertuis and Hadden (1951), Bach (1965), and Hauser *et al.* (2005)) produced mean stature differences greater than the standard error associated with each equation. Romano-British females had either shorter tibiae or shortened vertebral columns compared to reference populations of those formulae, overestimating final stature.

Table 6.44 *Paired t-tests comparing frequently cited formulae to Romano-British* _female_ *stature calculated using the revised Fully anatomical method Bonferroni-corrected α=0.0020*

	Fully Method Stature (cm) Fem. *N*=40	**Trotter and Gleser 1952/58-White** Fem. *N*=40	**Trotter and Gleser 1952/58-Black** Fem. *N*=40	**Pearson 1899** Fem. *N*=40	**Trotter 1970** Fem. *N*=40	**Vercellotti *et al.* 2009** Fem. *N*=40	**Olivier *et al.* 1978** Fem. *N*=40
Femur							
Max	163.25	164.14	161.33	159.49	164.14	164.05	162.58
Min	144.50	146.72	145.49	145.98	146.97	143.96	145.02
Ave	154.83	156.66	154.43	153.60	156.66	155.30	154.92
Paired *t*-Test		p<0.0010	p=0.4190	p=0.0130	p<0.0010	p=0.4030	p=0.8480
Tibia							
Max	163.25	165.35	160.36	158.98	165.35	161.28	159.69
Min	144.50	146.65	144.56	143.81	146.65	143.29	142.45
Ave	154.83	157.52	153.75	152.63	157.52	153.75	152.48
Paired *t*-Test		p<0.0010	p=0.0300	p<0.0010	p<0.0010	p=0.0380	p<0.0010
Femur + Tibia							
Max	163.25	164.83	161.07	159.60	164.89	162.77	161.53
Min	144.50	148.01	145.54	146.10	148.14	144.01	144.80
Ave	154.83	156.89	153.84	153.18	159.93	153.86	153.58
Paired *t*-Test		p<0.0010	p=0.0210	p<0.0010	p<0.0010	p=0.0150	p=0.0040

Table 6.44 cont.: *Paired t-tests comparing frequently cited formulae to Romano-British* <u>*female*</u> *stature calculated using the revised Fully anatomical method. Bonferroni-corrected α=0.0020.*

	Dupertuis and Hadden 1951 Fem *N*=40	**Breitinger 1937** Fem *N*=40	**Ross and Konigsberg 2002** Fem *N*=40	**Bach 1965** Fem *N*=40	**Hauser *et al* 2005** Fem *N*=40	**Černy and Komenda 1982** Fem *N*=40	**Allbrook 1961** Fem *N*=40
Femur							
Max	166.32	N/A	N/A	165.18	166.20	161.32	N/A
Min	150.18	N/A	N/A	156.06	148.20	145.28	N/A
Ave	159.28	N/A	N/A	161.21	158.36	154.33	N/A
Paired *t*-Test	p<0.0010	N/A	N/A	p<0.0010	p<0.0010	p=0.3160	N/A
Tibia							
Max	165.99	N/A	N/A	158.38	N/A	N/A	N/A
Min	148.99	N/A	N/A	147.13	N/A	N/A	N/A
Ave	158.87	N/A	N/A	153.67	N/A	N/A	N/A
Paired *t*-Test	p<0.0010	N/A	N/A	p=0.0220	N/A	N/A	N/A
Femur + Tibia							
Max	166.67	N/A	N/A	N/A	N/A	N/A	N/A
Min	150.35	N/A	N/A	N/A	N/A	N/A	N/A
Ave	158.87	N/A	N/A	N/A	N/A	N/A	N/A
Paired *t*-Test	p<0.0010	N/A	N/A	N/A	N/A	N/A	N/A

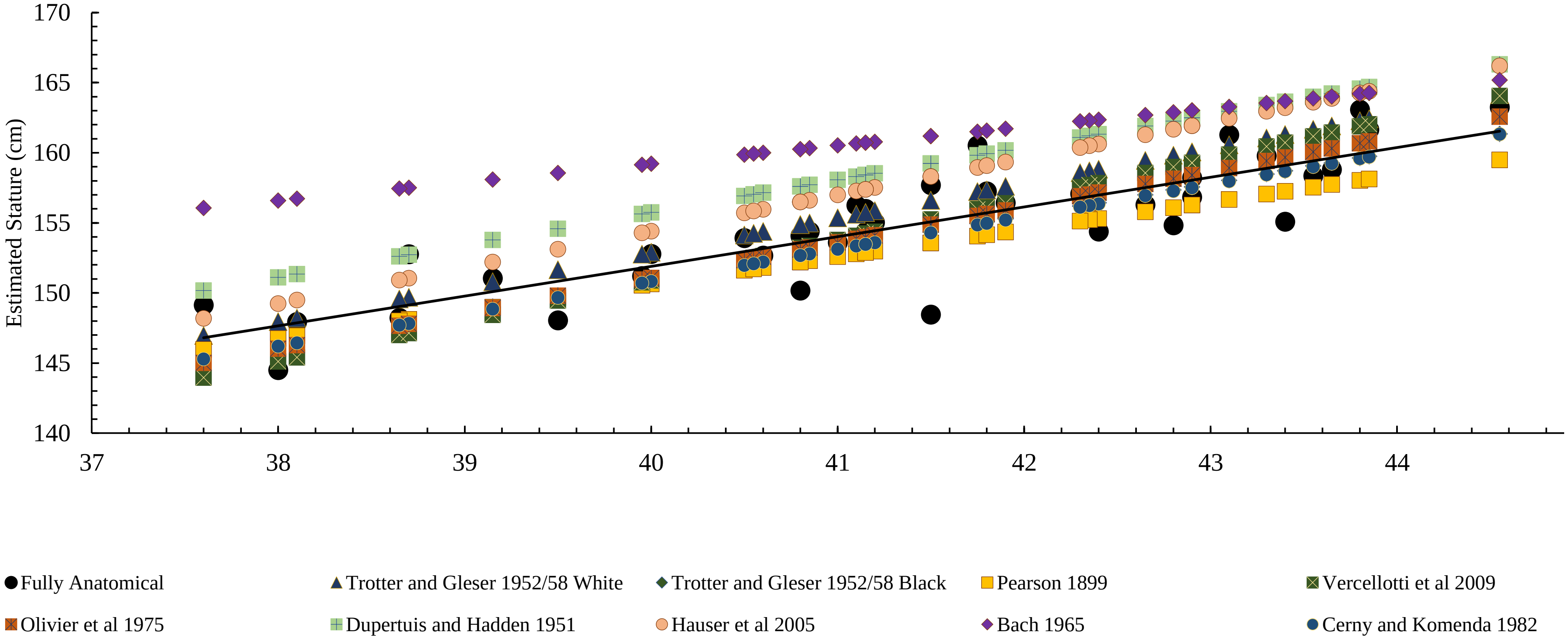


Figure 6.46: *Comparison of often cited mathematical regression formulae using maximum femur measurement and "known" stature of 40 Romano-British females. Black line represent linear regression of the "known" 40 females.*

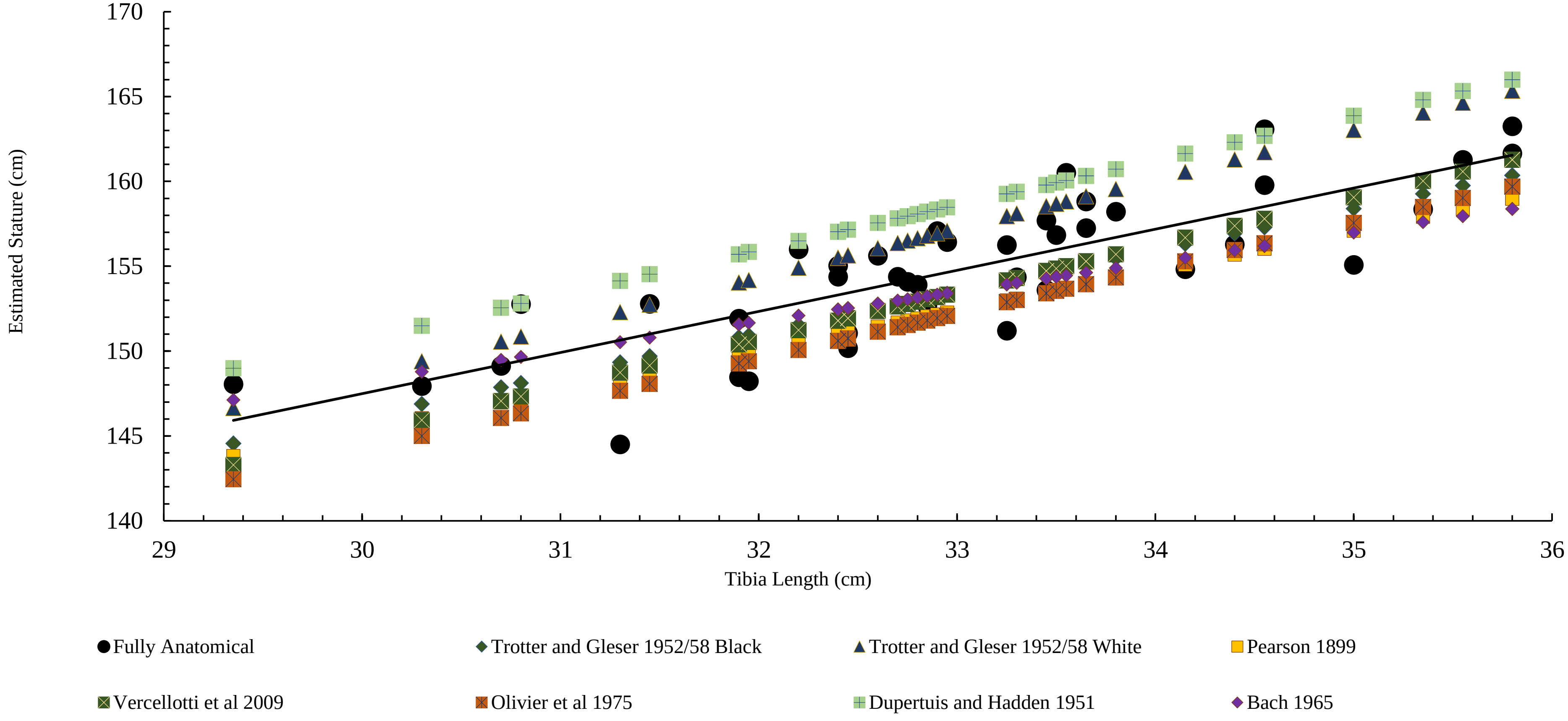


Figure 6.47: *Comparison of often cited mathematical regression formulae using tibia measurements and "known" stature of 40 Romano-British females. Black line represent linear regression of the "known" 40 females.*

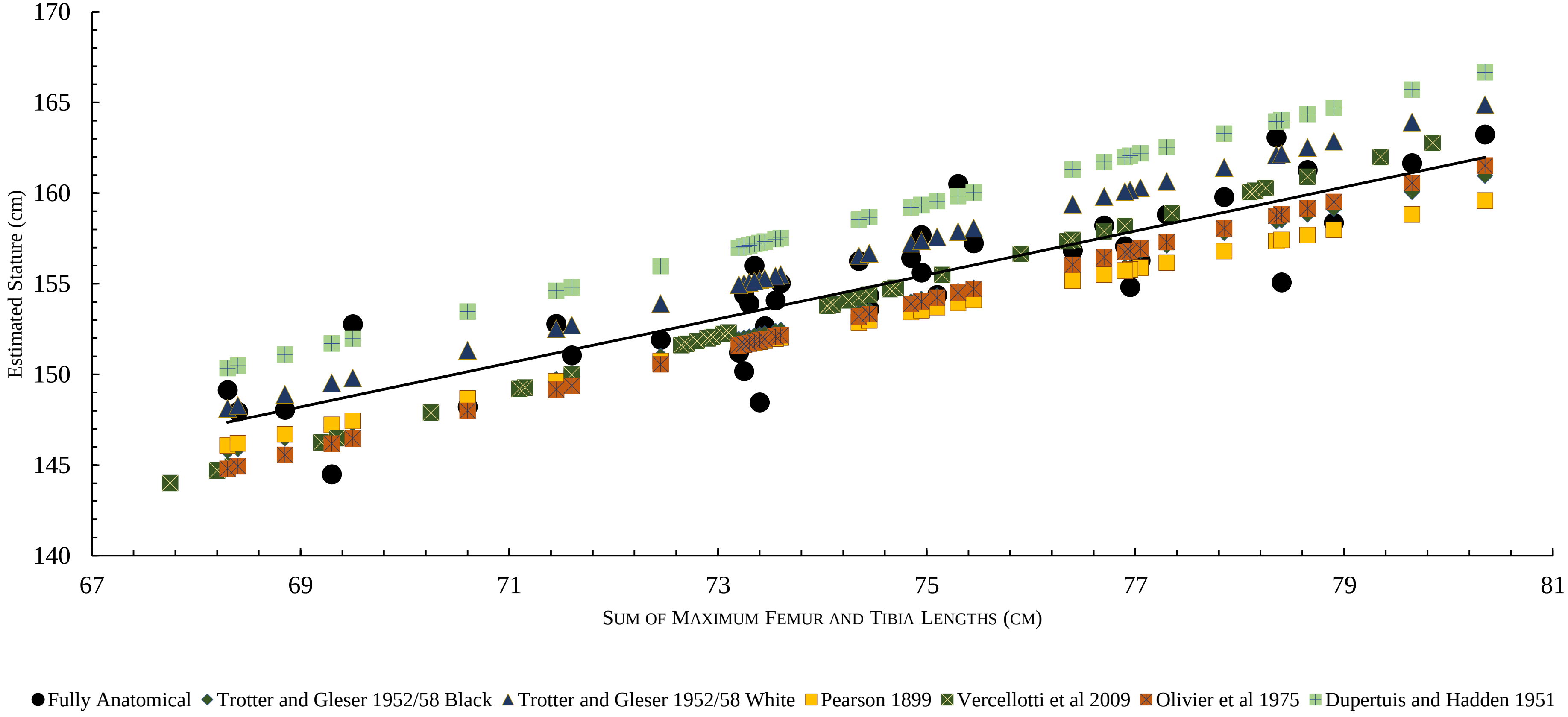


Figure 6.48: *Comparison of often cited mathematical regression formulae using the sum of maximum femur and tibia measurements and "known" stature of 40 Romano-British females. Black line represent linear regression of the "known" 40 females.*

Only seven formulae utilizing the length of the tibia were available to compare calculated stature to the Fully calculated ('known') stature of Romano-British females. Paired *t*-test demonstrated statistically significant differences between the Fully calculated statures and five stature calculated using various regression equations (Table 6.44). Unlike stature estimated using the maximum length of the femur, over half of the regression equations underestimated stature (Fig. 6.47). Equations that overestimated stature were Dupertuis and Hadden (1951) and Trotter (1970)/Trotter and Gleser (1952/58) 'white' formula. Of the two formulae, only Dupertuis and Hadden (1951) had a difference between the mean statures that was greater than the standard error. Based on tibial length, females whose final stature was underestimated by the five equations (Trotter and Gleser 1952/1958 'black' formula, Pearson 1899, Vercellotti *et al.* 2009, Olivier *et al.* 1978, and Bach 1965) could have had a greater proportion of the body composed of the femur or spinal column than the reference populations.

Finally, Fully calculated stature was compared to stature estimated using the sum of the maximum femoral and tibial lengths of seven regression equations (Fig. 6.48). Similar to those using tibial length, all five regression equations were statistically different to the 'known' stature of Romano-British females using paired *t*-tests. Only two of these equations (Trotter, (1970) and Dupertuis and Hadden (1951)) had a difference between the mean statures greater than standard error associated with each equation. Three of the five formulae tended to overestimate stature (Trotter and Gleser (1952/58) 'white' formula, Trotter (1970), and Dupertuis and Hadden (1951)) whilst two formulae (Pearson (1899) and Vercellotti *et al.* (2009)) seemed to underestimate final stature.

Mean percent prediction errors (mean PPE) are presented in Table 6.45. The equations with the lowest mean PPE for each long bone measurement, beside the population specific equations, was Vercellotti *et al.* (2009) maximum femur length, Trotter and Gleser (1952/58) 'black' formulae for tibial length, and summed maximum femur and tibia length. Estimates from Trotter and Gleser (1952/58) 'white' formulae and Dupertuis and Hadden (1951) formulae tended to overestimate stature in each of the three regression formulae. It was possible that the reference population could have greater length in the vertebral column, as the summed maximum femur and tibia within the Romano-British population were below estimated stature using these equations. Stature calculated using Trotter and Gleser (1952/58) 'black' formulae and Olivier *et* *al.* (1978) formulae were able to estimate stature fairly accurately using the maximum femur formulae, but underestimated stature slightly using the length of the tibia and the combined length of the maximum femur and tibia.

Table 6.45: *Mean percent prediction errors of formulae most commonly cited in bioarchaeological literature, using the Fully anatomical method as the "known" stature.*

Mean Percent Prediction Error (Mean PPE)		
Formula (Maximum Femur)	**Males**	**Females**
My Formula	0.059	0.007
Trotter and Gleser 1952/1958-White	2.917	0.974
Trotter and Gleser 1952/1958-Black	1.030	-0.445
Pearson 1899	0.605	-0.939
Trotter 1970	2.031	0.974
Olivier *et al*. 1978	2.224	0.045
Vercellotti *et al*. 2009	0.720	-0.153
Dupertuis and Hadden 1951	4.410	2.689
Breitinger 1937	2.164	N/A
Ross and Konigsberg 2002	2.796	N/A
Hauser *et al.* 2005	1.609	2.057
Bach 1965	0.710	4.050
Černy and Komenda 1982	3.077	-0.512
Formula (Tibia)	**Males**	**Females**
My Formula	0.066	0.026
Trotter and Gleser 1952/1958-White	2.136	1.622
Trotter and Gleser 1952/1958-Black	-0.728	-0.788
Pearson 1899	-0.805	-1.505
Trotter 1970	2.272	1.622
Olivier *et al*. 1978	1.207	-0.808
Vercellotti *et al*. 2009	-1.275	-1.623
Dupertuis and Hadden 1951	3.532	2.513
Allbrook 1961	0.679	N/A
Ross and Konigsberg 2002	1.286	N/A
Bach 1965	-3.881	-0.788
Formula (Femur+Tibia)	**Males**	**Females**
My Formula	0.036	0.013
Trotter and Gleser 1952/1958-White	2.266	1.187
Trotter and Gleser 1952/1958-Black	-0.246	-0.775
Pearson 1899	-0.043	-1.164
Trotter 1970	1.894	1.215
Olivier *et al*. 1978	1.304	-0.653
Vercellotti *et al*. 2009	-0.048	-0.950
Dupertuis and Hadden 1951	4.952	2.504

Due to the fact that the length of the femur was not statistically different in estimating stature, yet the length of the tibia and the combined length of the femur and tibiae were statistically different, the reference populations may have had shorter vertebral columns than the Romano-British female sample.

In summary, nine frequently cited mathematical regression formulae do not have the same body proportions as the sample being studied. For Romano-British females, some formulae were fairly accurate at estimating stature of this sample from a variety of long bone measurements. The ‘black’ mathematical regression formulae from Trotter and Gleser (1952/58) correlated most closely with ‘known’ stature.

6.4.3.2 Romano-British Males

Revised Fully anatomical stature calculations were compared to a maximum of 12 cited publications with linear regression formulae using measurements of maximum femoral length, tibial length, and the combined length of the maximum femur and tibia. Stature was estimated using these formulae and compared to the ‘known’ revised Fully anatomical stature calculated in a previous section of this chapter. The results are presented in Table 6.46. Similar to the female sample, the number of familywise comparisons (29) made an adjustment to the alpha level necessary to prevent Type I errors, therefore a Bonferroni-correction was utilised and lowered the level of significance to $\alpha=0.0017$.

Twelve regression equations were compared to the ‘known’ stature of Romano-British males (Fig. 6.49). Out of the 12 equations, seven produced a stature that was statistically different to the ‘known’ stature. Though seven equations were significantly different based on paired *t*-tests, three equations had a difference between the mean statures that was less than the standard error associated with each equation Therefore, six equations estimated Romano-British males to be taller than the ‘known’ stature by a margin greater than the standard error of each equation. These included formulae from Trotter and Gleser (1952/58) ‘white’ formula, Vercellotti *et al.* (2009), Dupertuis and Hadden (1951), Breitinger (1937), and Černy and Komenda (1982). Equations demonstrating smaller differences between mean statures were Pearson (1899), Olivier *et al.* (1978), and Bach (1965), which was reflected in their p-values. Those equations overestimating stature in Romano-British males most likely had reference populations that had greater lengths in tibiae and/or the vertebral column.

Ten equations were available to calculate stature using the length of the tibia (Fig. 6.50). When compared to ‘known’ Romano-British male stature, four were calculated as statistically different. Despite four equations having statistically significant differences in stature calculations, only two of these equations (Dupertuis and Hadden (1951) and Bach (1965)) had differences greater than the standard error associated with their equations. Stature estimated using Allbrook (1961) demonstrated the least difference in mean stature estimation. Stature estimated using the measurement of the length of the tibia both over- and under-estimated stature. Those equations that overestimated final stature using the tibia may have had a reference population with a greater proportion of the body dedicated to the length of the femur or vertebral column, whilst those who underestimated may have demonstrated shorter femoral or vertebral column length.

Finally, a total of seven regression equations using the combined length of the maximum femur and tibia were used to estimate stature (Fig. 6.51). The statures calculated from four regression equations from Trotter and Gleser (1952/58) 'white' formula, Trotter (1970), Vercellotti *et al.* (2009), and Dupertuis and Hadden (1951) were statistically different from 'known' stature of Romano-British males based on paired *t*-tests. All formulae overestimated stature, however the equation from Dupertuis and Hadden (1951) produced mean stature that was overestimated by greater than the standard error. Mean stature from Trotter and Gleser (1952/58) 'black' formula, Pearson (1899), and Olivier *et al.* (1978) had a difference of less than 0.62 cm compared to 'known' mean stature. Equations overestimating stature may reflect a reference sample with a greater length of either the femur or tibia along with greater length in the vertebral column, thus affecting body proportions.

Table 6.46: *Paired t-tests comparing frequently cited formulae to Romano-British* <u>*male*</u> *stature calculated using the revised Fully anatomical method. Bonferroni-corrected α=0.0017*

	Fully Method Stature (cm Male *N=36*	**Trotter and Gleser 1952/58-White** Male *N=36*	**Trotter and Gleser 1952/58-Black** Male *N=36*	**Pearson 1899** Male *N=36*	**Trotter 1970** Male *N=36*	**Vercellotti *et al.* 2009** Male *N*=36	**Olivier *et al*. 1978** Male *N=36*
Femur							
Max	174.43	178.86	174.81	173.14	177.67	179.00	174.37
Min	150.03	155.20	153.39	153.97	153.40	152.38	152.78
Ave	164.14	168.66	165.57	164.87	167.20	167.52	165.06
Paired *t*-Test		p<0.001	p=0.044	p=0.282	p<0.001	p<0.001	p=0.189
Tibia							
Max	174.43	174.74	169.35	169.78	175.26	174.70	169.00
Min	150.03	156.22	152.59	151.61	155.98	152.44	150.85
Ave	164.14	167.50	162.79	162.68	167.72	165.99	161.91
Paired *t*-Test		p<0.001	p=0.064	p=0.044	p<0.001	p=0.015	p=0.003
Femur + Tibia							
Max	174.43	176.71	171.80	172.21	176.39	176.58	172.31
Min	150.03	155.67	152.60	152.91	154.68	152.05	152.67
Ave	164.14	167.65	163.53	163.86	167.04	166.23	163.86
Paired *t*-Test		p<0.001	p=0.288	p=0.643	p<0.001	p<0.001	p=0.636

Table 6.46 cont.: *Paired t-tests comparing frequently cited formulae to Romano-British male stature calculated using the revised Fully anatomical method. Bonferroni-corrrected α=0.0017.*

	Dupertuis and Hadden 1951 Male *N*=36	**Breitinger 1937** Male *N*=36	**Ross and Konigsberg 2002** Male *N*=36	**Bach 1965** Male *N*=36	**Hauser *et al* 2005** Male *N*=36	**Černy and Komenda 1982** Male *N*=36	**Allbrook 1961** Male *N*=36
Femur							
Max	180.41	174.67	178.85	170.83	179.26	179.15	N/A
Min	158.83	157.89	154.76	157.44	149.68	155.43	N/A
Ave	171.11	167.43	168.46	165.05	166.51	168.92	N/A
Paired *t*-Test	p<0.001	p<0.001	p<0.001	p=0.203	p=0.008	p<0.001	N/A
Tibia							
Max	176.29	N/A	173.80	162.83	N/A	N/A	171.99
Min	159.63	N/A	154.13	149.48	N/A	N/A	154.39
Ave	169.78	N/A	166.11	157.61	N/A	N/A	165.10
Paired *t*-Test	p<0.001	N/A	p=0.008	p<0.001	N/A	N/A	p=0.181
Femur + Tibia							
Max	179.90	N/A	N/A	N/A	N/A	N/A	N/A
Min	161.67	N/A	N/A	N/A	N/A	N/A	N/A
Ave	172.08	N/A	N/A	N/A	N/A	N/A	N/A
Paired *t*-Test	p<0.001	N/A	N/A	N/A	N/A	N/A	N/A

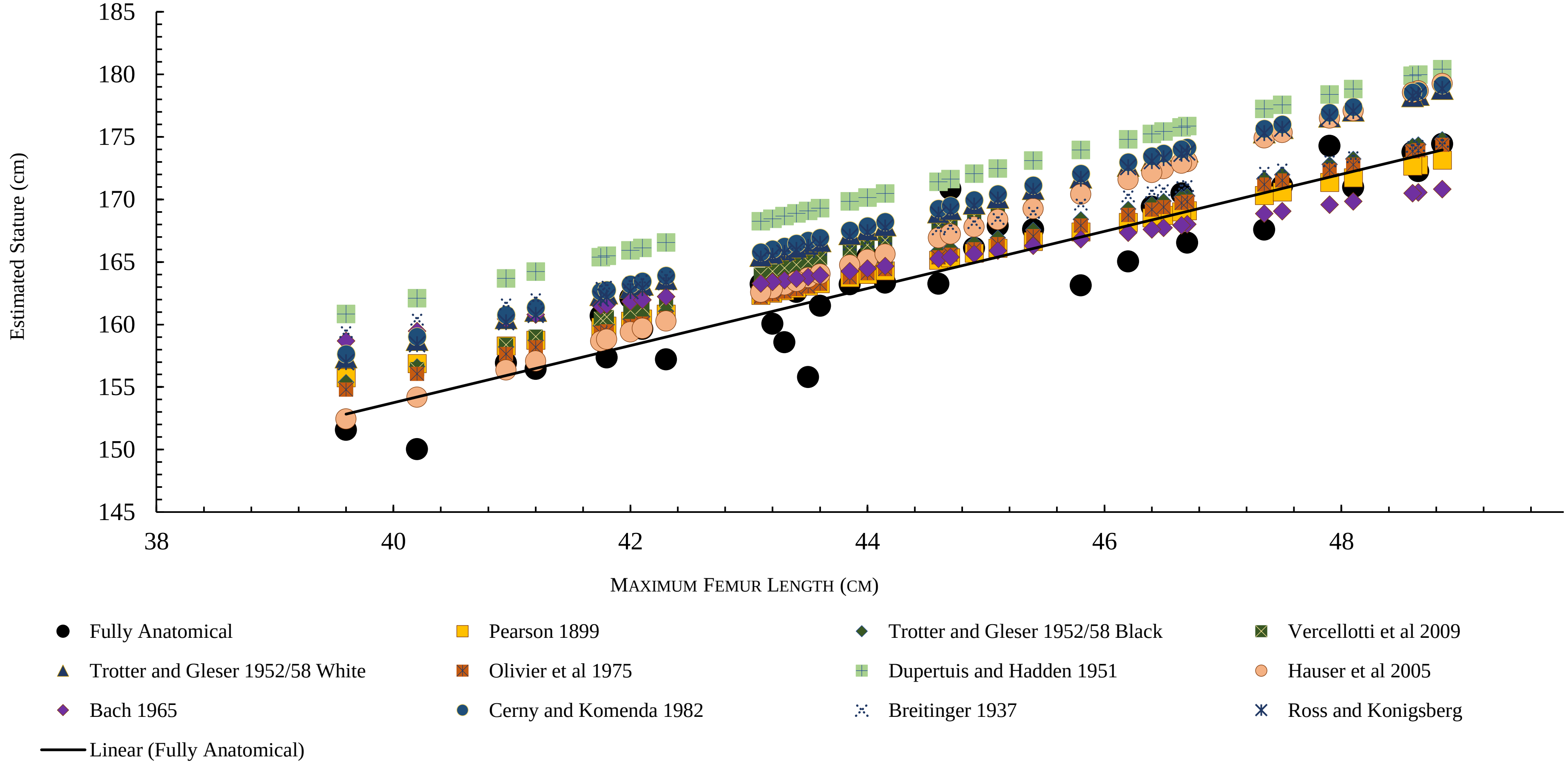


Figure 6.49: *Comparison of often cited mathematical regression formulae using the maximum length of the femur and "known" stature of 36 Romano-British males. Black line represent linear regression of the "known" 36 males.*

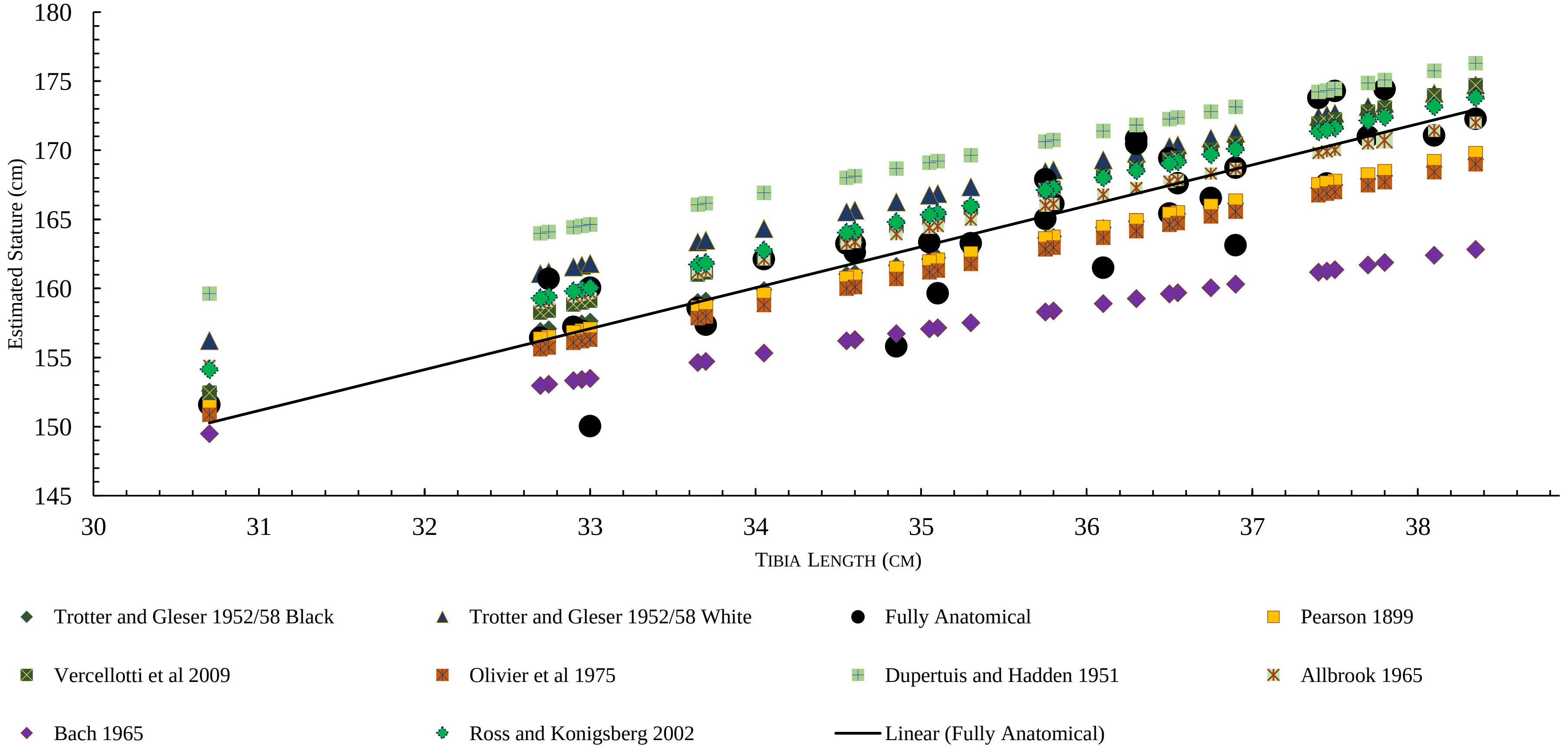


Figure 6.50: *Comparison of often cited mathematical regression formulae using the length of the tibia and "known" stature of 36 Romano-British males. Black line represent linear regression of the "known" 36 males.*

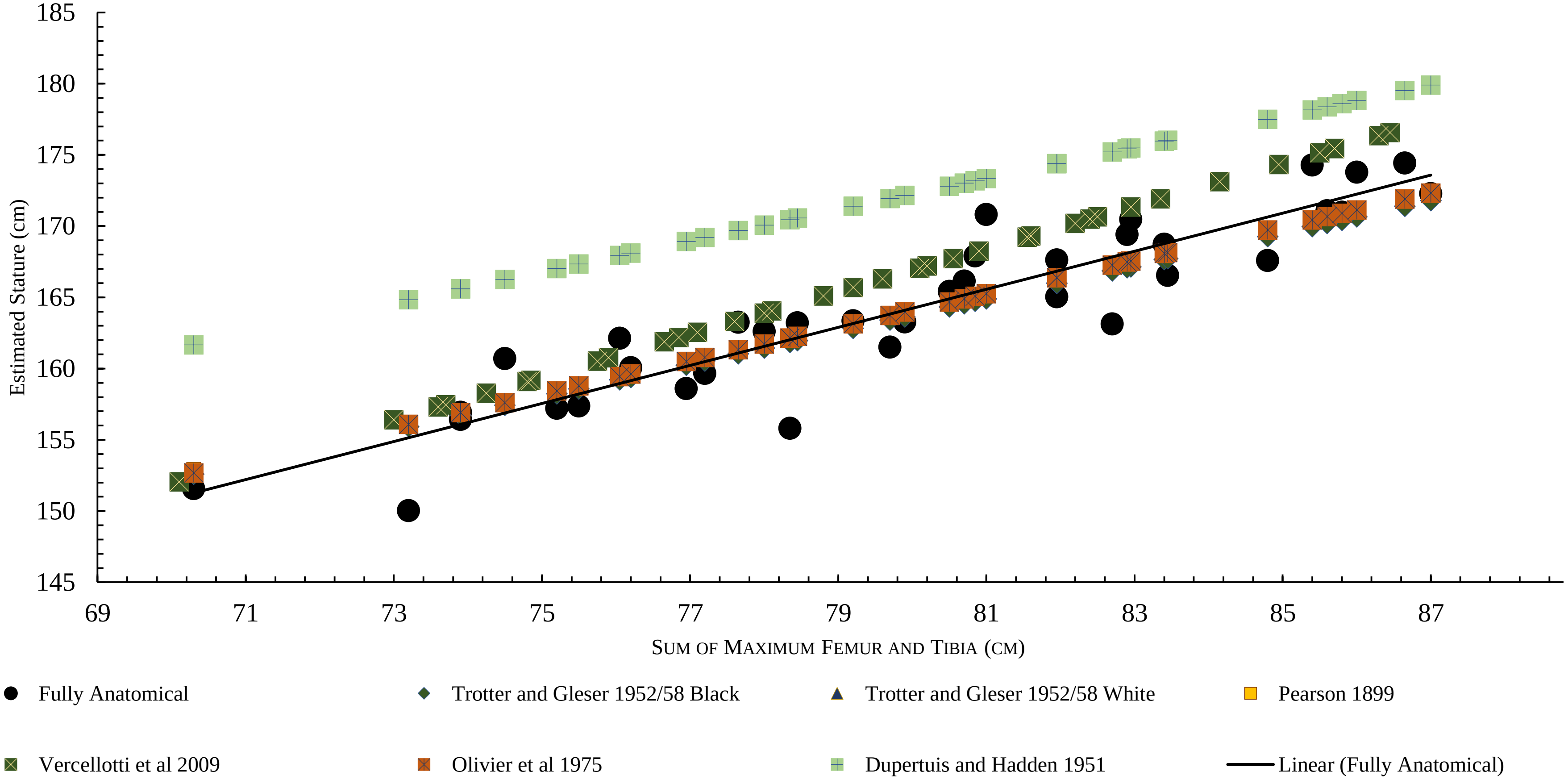


***Figure 6.51**: Comparison of often cited mathematical regression formulae using the maximum length of the femur and length of the tibia and "known" stature of 36 Romano-British males. Black line represent linear regression of the "known" 36 males.*

Mean percent prediction errors (mean PPE) were calculated for each formulae, including the population specific formulae listed in a previous section within this chapter (see Table 6.46). Publications that presented formulae using all three measurements were further analysed to determine how the reference sample may be different from the Romano-British male sample with regard to body proportions. Publications overestimating stature with many measurements (Trotter and Gleser (1952/58) 'white' formulae, Trotter (1970), Vercellotti *et al.* (2009), and Dupertuis and Hadden (1951)) most likely had a reference sample with a greater proportion and/or length within the vertebral column than the Romano-British males. Formulae from Trotter and Gleser (1952/58) 'black', Pearson (1899), and Olivier *et al.* (1978) slightly overestimated stature using femoral measurements, but underestimated stature using tibial measurements and the combined length of the maximum femur and tibia. It is likely that the reference samples had a smaller proportion of the body composed of the tibia and/or shorter vertebral column than Romano-British males.

In summary, these often cited formulae do not accurately estimate stature due to variations in body proportions, particularly within the vertebral column. Unlike the Romano-British females, the publications that had the fewest differences between calculated stature and Fully anatomical stature from various long bones were Pearson (1899) and Olivier *et al.* (1978). Though they slightly underestimate stature when using tibial length, the formulae from these two publications provide the closest stature estimation aside from the population specific formulae.

6.4.3.3 Early Medieval Females

A maximum of ten cited publications with mathematical regression formulae were used to calculate stature of Early Medieval females using the maximum length of the femur, length of the tibia, and the combined length of the femur and tibia. These estimated statures were compared using paired *t*-tests to the 'known' statures of eight Early Medieval females using the Fully anatomical method. Summary statistics presenting the maximum, minimum, and mean stature calculated from all formulae are presented in Table 6.47. Again, the adjusted alpha level for females was $\alpha=0.0020$.

Within the female sample, a total of nine equations (those from Trotter and Gleser (1952/58) and Trotter (1970) had the same maximum femur formulae) were used to calculate stature for the Early Medieval females. From these nine equations, all except one (Trotter and Gleser (1952/58) 'black' equation) overestimated stature (Fig. 6.52). Surprisingly, only one equation (Trotter and Gleser (1952/1958) 'white'/Trotter (1970)) was statistically different to the 'known' stature. Three formulae (Vercellotti *et al.* (2009), Dupertuis and Hadden (1951), and Bach (1965)) had a difference between mean statures greater than the standard error associated with each equation. The formula demonstrating the least amount of variation from the 'known' stature was Pearson (1899) (only 0.19 cm difference between mean statures). As with Romano-British females, the formula which overestimates stature using the maximum femoral length was Bach (1965).

Only eight formulae using the length of the tibia were available to estimate stature for Early Medieval females. Only one of the eight equations displayed any statistically significant differences to the 'known' stature (Trotter and Gleser (1952/1958) 'white' and Trotter (1970)). Three formulae (Trotter and Gleser (1952/58) 'white' formula, Trotter (1970), and Dupertuis and Hadden (1951)) also had differences between mean statures that were greater than the standard errors associated with each equation. Once again, all equations using the tibia, except for Pearson (1899), tended to overestimate stature (Fig. 6.53). Calculations from both Pearson (1899) and Olivier *et al.* (1978) exhibited mean differences from the anatomical method that were less than 0.05 cm. Unlike the calculations from the maximum femur, Bach's (1965) formulae overestimate stature with only a 0.55 cm difference between the means. The formulae with the greatest accuracy at estimating stature from tibial length was Pearson (1899).

Finally, stature was estimated using formulae derived from the combined length of maximum femur and tibia. Once again, only two published equations overestimated the stature of Early Medieval females to varying degrees (Fig. 6.54). Two regression formulae (Trotter and Gleser (1952/58) 'white' formula, Trotter (1970)), were statistically different to the 'known' stature of females within this sample. Differences between the estimated mean stature and the 'known' mean stature estimations were greater than the standard errors associated with each formula. Similar to stature estimated using the maximum femur and tibial lengths, the formula with the closest mean stature to the 'known' estimation was Pearson (1899).

Table 6.47: *Paired t-tests comparing frequently cited formulae to Early Medieval* female *stature calculated using the revised Fully anatomical method. Bonferroni-corrected α=0.0020*

	Fully Method Stature (cm) Fem *N*=8	**Trotter and Gleser 1952/58-White** Fem *N*=8	**Trotter and Gleser 1952/58-Black** Fem *N*=8	**Pearson 1899** Fem *N*=8	**Trotter 1970** Fem *N*=8	**Vercellotti *et al.* 2009** Fem *N*=8	**Olivier *et al.* 1978** Fem *N*=8
Femur							
Max	158.00	161.55	158.94	157.45	161.55	161.02	159.92
Min	149.54	150.80	149.02	148.99	150.80	148.44	148.93
Ave	154.43	157.95	155.62	154.62	157.95	156.81	156.24
Paired T-Test		p=0.004	p=0.188	p=0.815	p=0.004	p=0.041	p=0.074
Tibia							
Max	158.00	165.21	160.24	158.86	165.21	161.14	159.56
Min	149.54	154.77	151.42	150.39	154.77	151.10	149.94
Ave	154.43	159.70	155.58	154.39	159.70	155.84	154.48
Paired T-Test		p<0.001	p=0.156	p=0.950	p<0.001	p=0.086	p=0.943
Femur + Tibia							
Max	158.00	161.67	158.26	157.02	161.69	159.98	158.33
Min	149.54	152.48	149.54	149.74	152.65	149.90	149.31
Ave	154.43	158.62	155.36	154.61	158.69	156.64	155.34
Paired T-Test		p<0.001	p=0.125	p=0.736	p<0.001	p=0.004	p=0.107

Table 6.47 cont.: *Paired t-tests comparing frequently cited formulae to Early Medieval* <u>*female*</u> *stature calculated using the revised Fully anatomical method. Bonferroni-corrected α=0.0020.*

	Dupertuis and Hadden 1951 Fem *N*=8	**Breitinger 1937** Fem *N*=8	**Ross and Konigsberg 2002** Fem *N*=8	**Bach 1965** Fem *N*=8	**Hauser *et al* 2005** Fem *N*=8	**Černy and Komenda 1982** Fem *N*=8	**Allbrook 1961** Fem *N*=8
Femur							
Max	163.88	N/A	N/A	163.81	163.48	158.89	N/A
Min	153.78	N/A	N/A	158.09	152.21	148.86	N/A
Ave	160.50	N/A	N/A	161.89	159.71	155.53	N/A
Paired T-Test	p=0.008	N/A	N/A	p=0.008	p=0.007	p=0.203	N/A
Tibia							
Max	165.85	N/A	N/A	158.29	N/A	N/A	N/A
Min	156.37	N/A	N/A	152.01	N/A	N/A	N/A
Ave	160.85	N/A	N/A	154.98	N/A	N/A	N/A
Paired T-Test	p=0.008	N/A	N/A	p=0.383	N/A	N/A	N/A
Femur + Tibia							
Max	163.55	N/A	N/A	N/A	N/A	N/A	N/A
Min	154.75	N/A	N/A	N/A	N/A	N/A	N/A
Ave	160.63	N/A	N/A	N/A	N/A	N/A	N/A
Paired T-Test	p=0.008	N/A	N/A	N/A	N/A	N/A	N/A

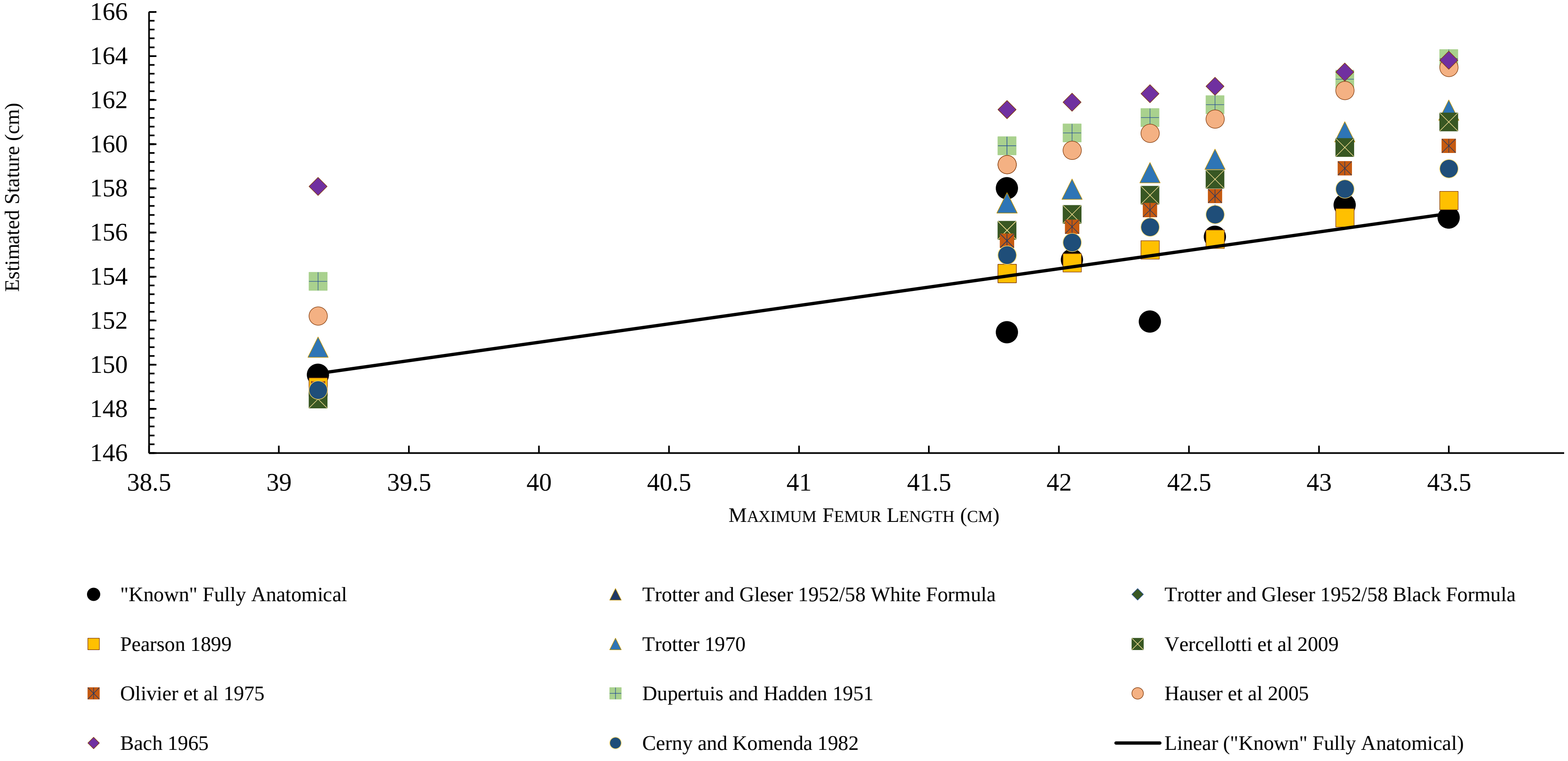


Figure 6.52: *Comparison of frequently cited mathematical regression formulae using the maximum length of the femur and "known" stature of eight Early Medieval females. Th black line represent linear regression of the "known" eight females.*

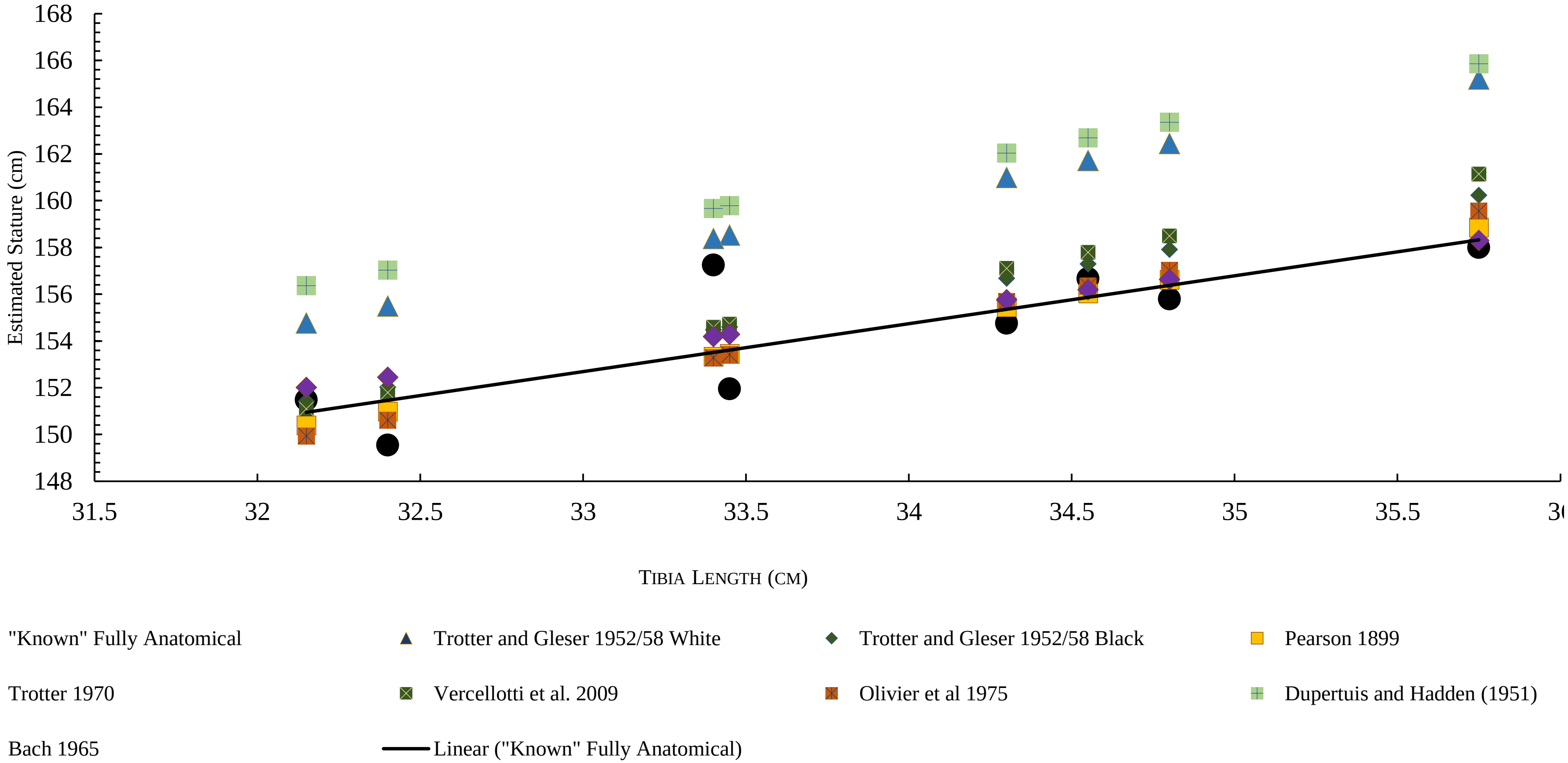


Figure 6.53: *Comparison of frequently cited mathematical regression formulae using the length of the tibia and "known" stature of eight Early Medieval females. The black line represent linear regression of the "known" eight females.*

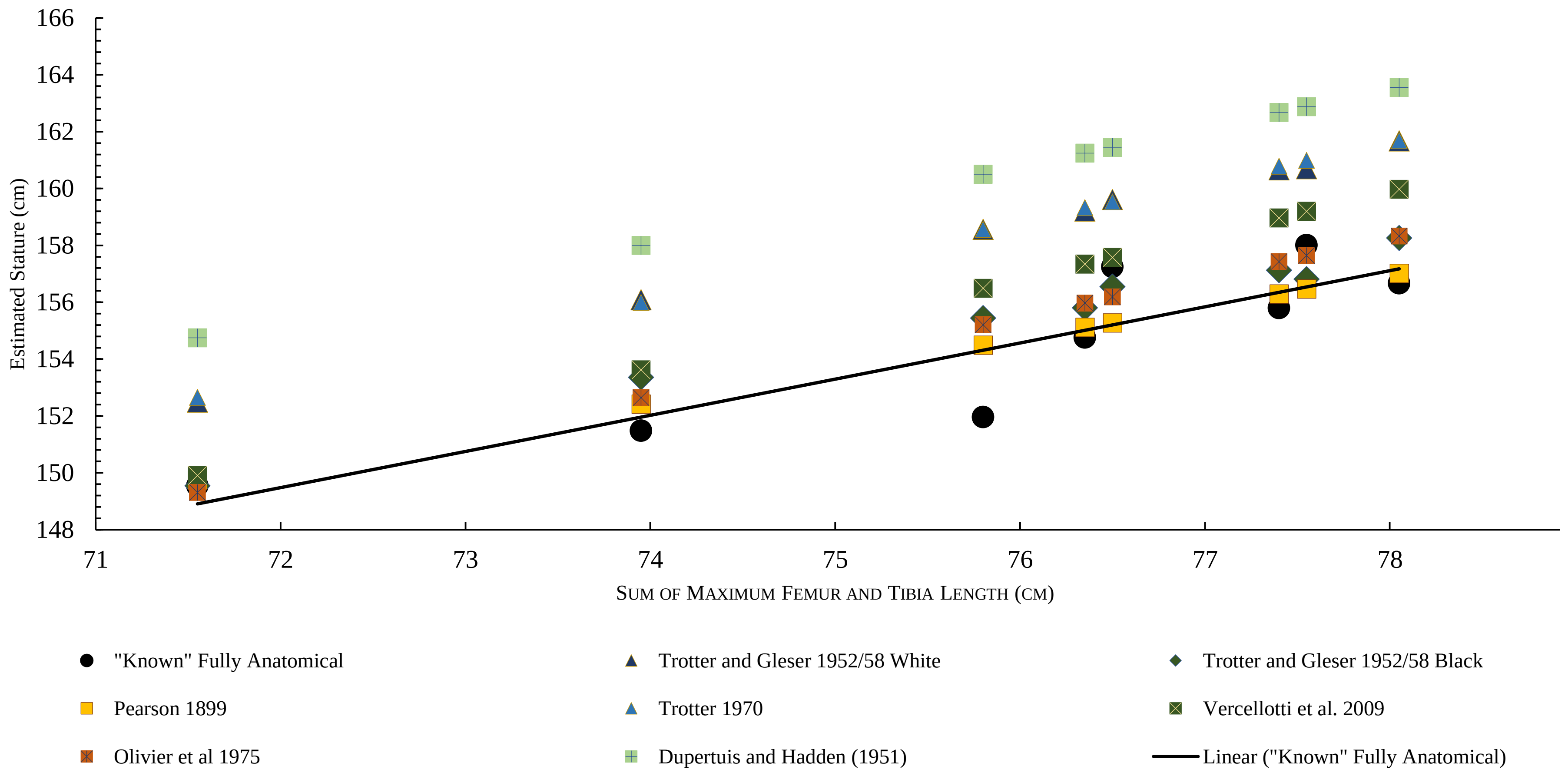


Figure 6.54: *Comparison of frequently cited mathematical regression formulae using the maximum length of the femur and tibia and "known" stature of eight Early Medieval females. The black line represent linear regression of the "known" eight females.*

Mean percent prediction errors are presented in Table 6.48. The regression formula with the lowest mean PPE was Pearson's (1899) equation using tibial length. Pearson (1899) also demonstrated the lowest mean PPE within maximum femur and summed maximum femur and tibia.

Table 6.48: *Mean percent prediction errors of formulae most commonly cited in bioarchaeological literature, when the Fully anatomical method is used as the "known" stature of Early Medieval individuals.*

Mean Percent Prediction Error (Mean PPE)		
Formula (Maximum Femur)	**Males**	**Females**
My Formula	0.027	0.016
Trotter and Gleser 1952/1958-White	2.018	2.287
Trotter and Gleser 1952/1958-Black	0.087	0.781
Pearson 1899	-0.407	0.136
Trotter 1970	1.168	2.287
Vercellotti *et al*. 2009	1.437	1.543
Olivier *et al*. 1978	-0.213	1.183
Dupertuis and Hadden 1951	3.416	3.940
Breitinger 1937	1.045	N/A
Ross and Konigsberg 2002	1.914	N/A
Hauser *et al.* 2005	0.931	3.426
Bach 1965	-0.499	4.855
Černy and Komenda 1982	2.177	0.725
Formula (Tibia)	**Males**	**Females**
My Formula	0.036	0.012
Trotter and Gleser 1952/1958-White	2.567	3.412
Trotter and Gleser 1952/1958-Black	-0.451	0.753
Pearson 1899	-0.364	-0.019
Trotter 1970	2.788	3.412
Vercellotti *et al*. 2009	2.082	0.917
Olivier *et al*. 1978	-0.828	0.037
Dupertuis and Hadden 1951	3.728	4.161
Allbrook 1961	1.029	N/A
Ross and Konigsberg 2002	1.857	N/A
Bach 1965	-3.941	0.370
Formula (Femur+Tibia)	**Males**	**Females**
My Formula	0.026	0.005
Trotter and Gleser 1952/1958-White	2.114	2.720
Trotter and Gleser 1952/1958-Black	-0.490	0.611
Pearson 1899	-0.327	0.123
Trotter 1970	1.798	2.765
Vercellotti *et al*. 2009	1.782	1.429
Olivier *et al*. 1978	-0.263	0.593
Dupertuis and Hadden 1951	3.247	4.022

Formulae which utilised the maximum length of the femur, length of the tibia, and the combined length of the femur and tibia were further analysed to detect possible differences between the Early Medieval female sample and reference sample with regard to body proportions. Formulae that overestimated stature in all three measurements (Trotter and Gleser (1952/58) 'white' formula, Trotter (1970), Vercellotti *et al.* (2009), and Dupertuis and Hadden (1951)) may have had reference samples in which the trunks were proportionally longer. Trotter and Gleser's (1952/58) 'black' formula demonstrate variation between the reference sample and the Early Medieval female sample with respect to the crural index (ratio of femur to tibia) and length of the vertebral column. The two publications with proportions most similar to the Early Medieval females were Pearson (1899) and Olivier *et al.* (1978), as the differences seen in each set of formulae were minimal. These results highlight the relevance of the vertebral column in the estimation of stature and the importance of population specific regression formulae as great variation exists between populations with regard to body proportions.

To summarize, Early Medieval females exhibited slightly different body proportions to a few of the reference samples in the publications listed above. Some publications provided fairly accurate estimates from formulae using the maximum length of the femur, however, these same publications may not have accurately estimated stature using the tibial length or the combined length of the femur and tibia. Pearson (1899) was found to be most closely correlated with 'known' stature and therefore may have a reference sample with the closest body proportions to this female sample.

6.4.3.4 Early Medieval Males

'Known' stature of 15 Early Medieval males were compared to mathematical regression equations from a maximum of 12 publications (Fig. 6.55). Summary statistics and paired *t*-test p-values are presented in Table 6.49. Four of the 12 regression equations using the maximum femoral length demonstrated statistically significant differences between estimated and 'known' stature of Early Medieval males. These four equations include those from Trotter and Gleser (1952/58) 'white' formula, Ross and Konigsberg (2002), Dupertuis and Hadden (1951), and Černy and Komenda (1982). Only two formulae (Dupertuis and Hadden (1951) and Černy and Komenda

(1982)) exhibited differences that were greater than the standard error associated with each equation. Overall, eight equations tended to overestimate stature of males, whilst only four seemed to underestimate stature. Trotter and Gleser's (1952/58) 'black' formula was the most accurate at estimating stature from the maximum length of the femur, with a difference of only 0.01 cm between the 'known' and estimated mean stature.

Ten equations were available to estimate stature of Early Medieval males using the length of the tibia. Five equations were statistically different from the 'known' stature, with all (Trotter and Gleser (1952/58) 'white' formula, Trotter (1970), Vercellotti *et al*. (2009), Dupertuis and Hadden (1951), and Bach (1965)) demonstrating mean stature estimates that were greater than the standard error associated with each formula. Equations that under-estimated stature included Trotter and Gleser (1952/58) 'black' formula, Pearson (1899), Olivier *et al.* (1978), and Bach (1965) (Fig. 6.56). The equation with the closest mean stature to the 'known' stature was Pearson (1899) with a difference of only 0.77 cm. This was followed by the 'black' formula from Trotter and Gleser (1952/58).

Finally, stature of Early Medieval males was estimated using the sum of the maximum length of the femur and tibia (Fig. 6.57). Fewer publications report regression formulae using the combination of these measurements, with only seven equations available for comparison. A total of four equations (Trotter and Gleser (1952/58) 'white' formula, Trotter (1970), Vercellotti *et al*. (2009), and Dupertuis and Hadden (1951)) had stature estimates that were statistically different to the 'known' population. Only two formulae (Dupertuis and Hadden (1951) and Vercellotti *et al.* (2009)) presented mean statures that differed from the anatomical method by greater than the standard error associated with their equation. The equation with the lowest difference between mean statures was Olivier *et al.* (1978) with only a 0.58 cm difference.

Mean percent prediction errors for all equations are presented in Table 6.48. The published formula with the lowest mean PPE came from Trotter and Gleser's (1952/58) 'black' formula using the maximum length of the femur. Though this publication had the lowest mean PPE overall, Pearson (1899) and Olivier *et al.* (1978) had the lowest mean PPE within the formulae using the length of the tibiae and combined length of the femur and tibia, respectively. The seven publications that had formulae available for all three measurements were analysed further to assess possible differences between their reference sample and the Early Medieval male sample. Publications overestimating stature from all three forms of regression formulae might be more likely to have reference sample with different proportions within the crural index as well as greater length and/or proportion within the vertebral column. These publications include Trotter and Gleser's (1952/58) 'white' formula, Trotter (1970), Vercellotti *et al.* (2009), and Dupertuis and Hadden (1951). Olivier *et al.* (1978) equations overestimate stature using the maximum femoral length, whilst underestimating height using tibial length and combined femur and tibial length. Their reference population could conceivably have had shorter tibiae or shorter vertebral column length in comparison to Early Medieval males. The final two equations, Pearson (1899) and Trotter and Gleser's (1952/58) 'black' formula, all underestimated stature slightly. Again, these results emphasizes the role of the vertebral column in living stature as well as the need for population specific formulae to estimate stature of past populations. Body proportions of reference samples must be taken into consideration before applying these formulae to calculate stature.

6.4.4 Summary

In summary, frequently cited mathematical regression formulae from one publication often do not possess multiple formulae that accurately estimate stature for males within the Early Medieval period. Formulae from three publications accurately estimated stature for males from this period. The maximum length of the femur from Trotter and Gleser (1952/58) 'black' formula, Pearson (1899) tibial length formula, and Olivier *et al.* (1978) formula combining the length of the maximum femur and tibia had the fewest differences. Once again, these differences display the important role body proportions have on final stature. It is vital to try and assess whether reference populations from publications with mathematical regression formulae for calculating stature have similar body proportions to the target population.

Table 6.49: *Paired t-tests comparing frequently cited formulae to Early Medieval* <u>*male*</u> *stature calculated using the revised Fully anatomical method. Bonferroni-corrected α=0.0017.*

	Fully Method Stature (cm) Male *N*=15	**Trotter and Gleser 1952/58-White** Male *N*=15	**Trotter and Gleser 1952/58-Black** Male *N*=15	**Pearson 1899** Male *N*=15	**Trotter 1970** Male *N*=15	**Vercellotti *et al.* 2009** Male *N*=15	**Olivier *et al.* 1978** Male *N*=15
Femur							
Max	188.78	186.87	182.05	179.63	185.88	188.00	181.67
Min	149.56	156.71	154.75	155.19	154.94	154.07	154.16
Ave	167.16	170.41	167.15	166.29	169.00	169.49	166.66
Paired T-Test		p=0.001	p=0.997	p=0.416	p=0.035	p=0.007	p=0.587
Tibia							
Max	188.78	188.77	182.05	183.56	189.88	191.58	182.77
Min	149.56	160.10	156.10	155.41	160.02	157.09	154.65
Ave	167.16	171.28	166.21	166.39	171.66	170.54	165.61
Paired T-Test		p<0.001	p=0.396	p=0.450	p<0.001	p=0.001	p=0.142
Femur + Tibia							
Max	188.78	188.62	182.67	182.93	188.68	191.58	183.43
Min	149.56	157.31	154.09	154.27	156.37	154.30	154.20
Ave	167.16	170.57	166.20	166.47	170.05	170.09	166.58
Paired T-Test		p<0.001	p=0.283	p=0.434	p=0.001	p<0.001	p=0.853

Table 6.49 cont.: *Paired t-tests comparing frequently cited formulae to Early Medieval male stature calculated using the revised Fully anatomical method. Bonferroni-corrected α=0.0017.*

	Dupertuis and Hadden 1951 Male *N*=15	**Breitinger 1937** Male *N*=15	**Ross and Konigsberg 2002** Male *N*=15	**Bach 1965** Male *N*=15	**Hauser *et al* 2005** Male *N*=15	**Černy and Komenda 1982** Male *N*=15	**Allbrook 1961** Male *N*=15
Femur							
Max	187.71	180.34	187.00	175.36	189.27	187.17	N/A
Min	160.21	158.96	156.29	158.29	151.57	156.94	N/A
Ave	172.71	168.68	170.24	166.05	168.70	170.68	N/A
Paired T-Test	p<0.001	p=0.219	p=0.001	p=0.453	p=0.063	p<0.001	N/A
Tibia							
Max	188.92	N/A	188.70	172.95	N/A	N/A	185.33
Min	163.12	N/A	158.23	152.27	N/A	N/A	158.07
Ave	173.18	N/A	170.11	160.34	N/A	N/A	168.70
Paired T-Test	p<0.001	N/A	p=0.007	p<0.001	N/A	N/A	p=0.157
Femur + Tibia							
Max	188.29	N/A	N/A	N/A	N/A	N/A	N/A
Min	161.65	N/A	N/A	N/A	N/A	N/A	N/A
Ave	172.94	N/A	N/A	N/A	N/A	N/A	N/A
Paired T-Test	p<0.001	N/A	N/A	N/A	N/A	N/A	N/A

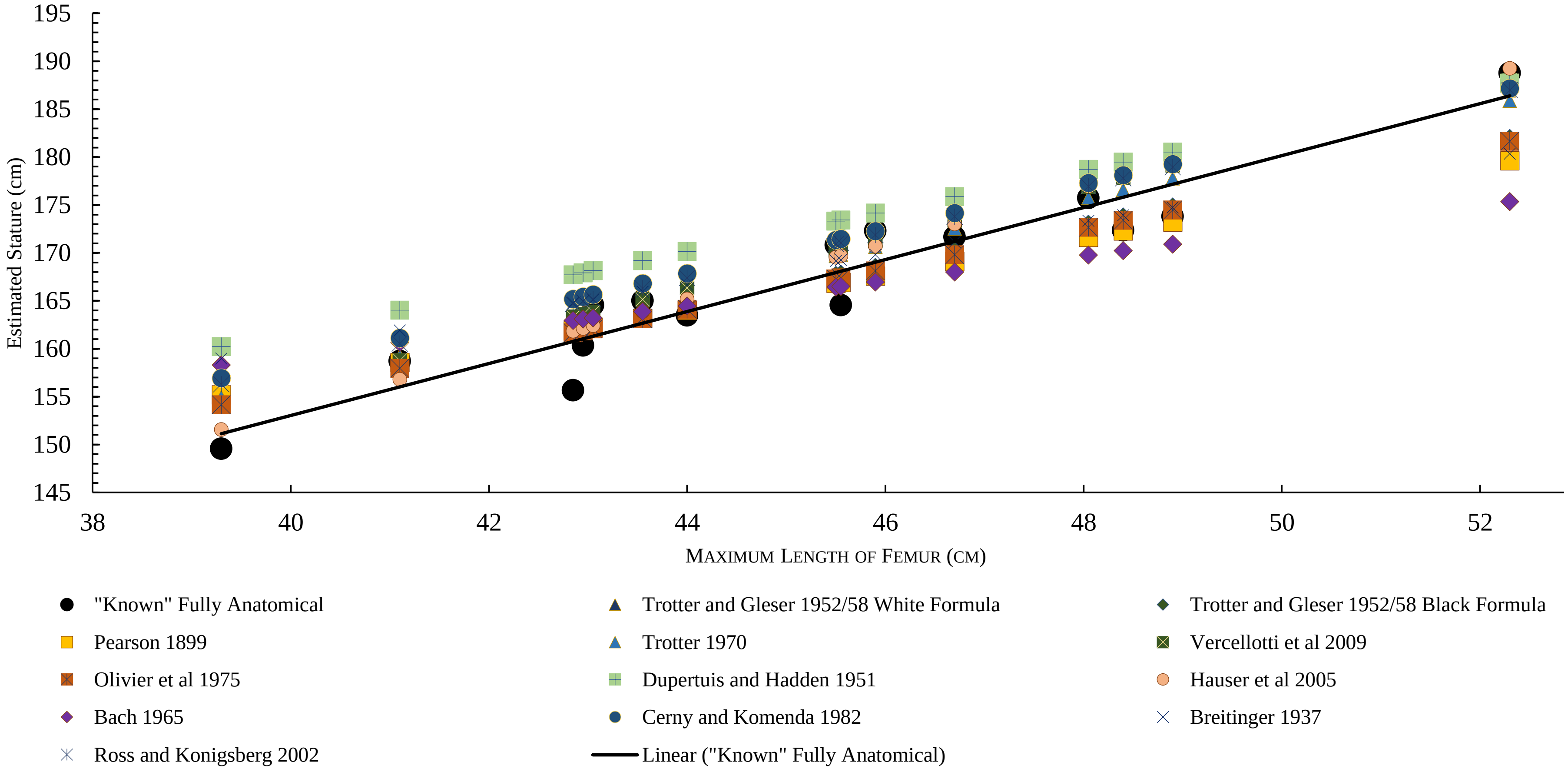


Figure 6.55: *Comparison of frequently cited mathematical regression formulae using the maximum length of the femur and "known" stature of 15 Early Medieval males. Black line represent linear regression of the "known" 15 males.*

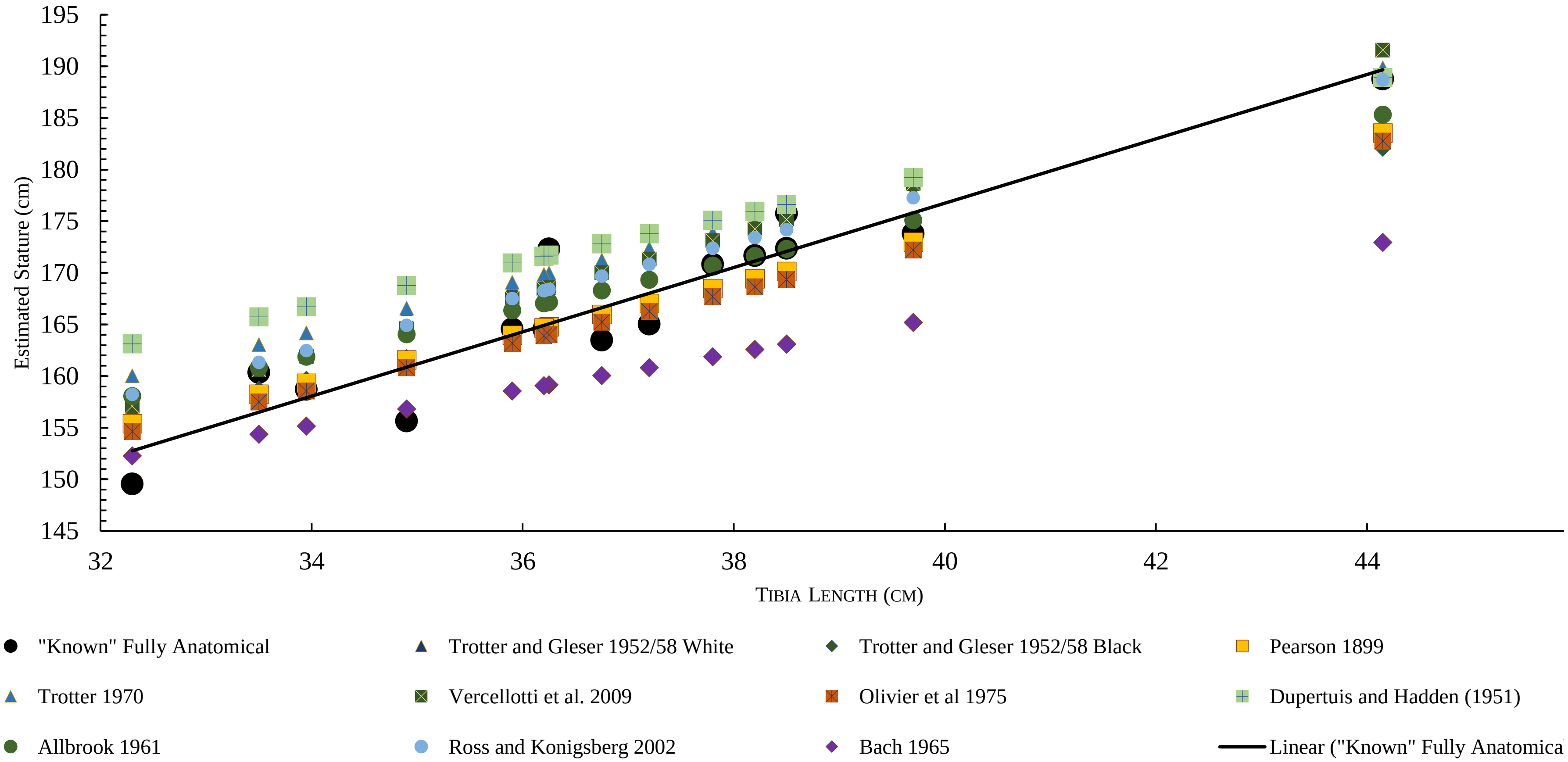


Figure 6.56: *Comparison of frequently cited mathematical regression formulae using the length of the tibia and "known" stature of 15 Early Medieval males. Black line represent linear regression of the "known" 15 males.*

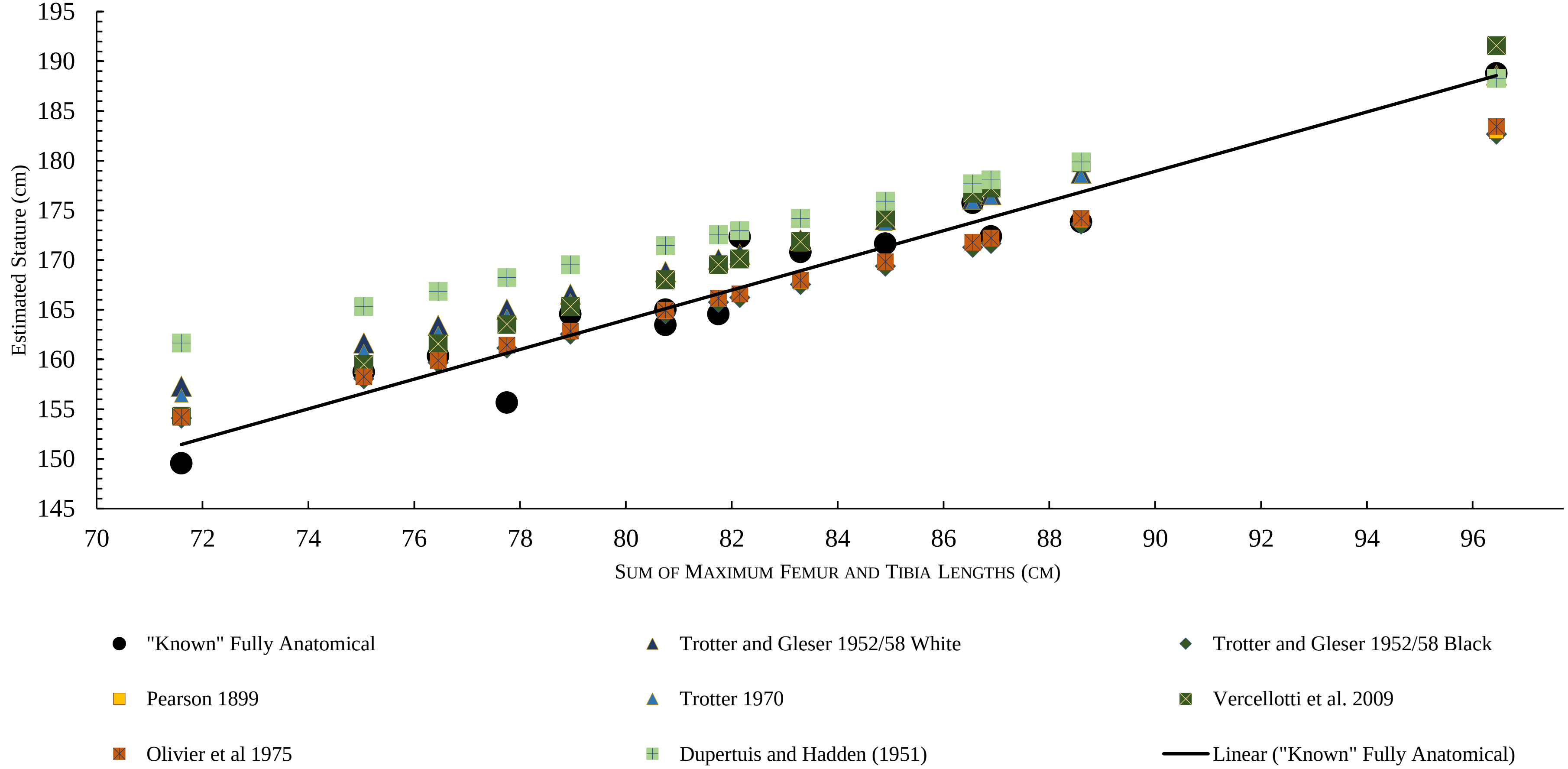


Figure 6.57: *Comparison of frequently cited mathematical regression formulae using the maximum length of the femur and length of the tibia and "known" stature of 15 Early Medieval males. Black line represent linear regression of the "known" 15 males*

6.5 Body Proportions of Romano-British and Early Medieval Samples

The last section of this results chapter will present information on long bone lengths in order to determine what information may be lost when using long bone lengths alone to interpret temporal trends in stature (research question number seven), as well as various body proportion indices from the Romano-British and Early Medieval samples in order to address research questions 3, 4, and 6. Analysis of body proportions have been used to assess climatic variation in humans (Holliday 1997a, Holliday and Ruff 1997), migration from different climatic environments (Temple and Mastumura, 2011), and intra-population variation associated with possible stress experienced during growth and development (Vercellotti *et al.,* 2011). Variation in limb lengths demonstrate this interplay of genetics and environmental conditions. Typically, higher latitude populations tend to display lower brachial and crural index values. These lower values tend to represent individuals with 'cold-adapted' bodies. The opposite remains true for higher brachial and crural index values (more equal proximal and distal limb segments), typically seen in lower latitude regions or more tropical environments (Ruff, 1994; Holliday, 1997b, Kurki *et al.,* 2008; Holliday and Hilton, 2010). This section presents the results of the assessment of nine indices including brachial, crural, intermembral, humerofemoral, and brachiocrural indices, along with skeletal torso height, relative lower limb length, relative upper limb length compared to torso height, and relative torso length. Before assessing these indices, measurements of the four long bones: the humerus, radius, femur, and tibia, will be analysed for potential differences between females and males, as well as site or regional locations. These measurements will also be compared between the two periods to assess differences during this transitional period in history.

6.5.1 Long bone measurements

Most mathematical regression formulae utilize the lengths of long bones to calculate final stature. Some researchers have stated that long bone lengths should be used as a proxy instead of calculated stature from regression formulae, which may introduce an additional source of error due to population specific differences in body proportions (Brothwell and Zakrzewski, 2004; Goldewijk and Jacobs, 2013). Prior to presenting results on body proportions, summary statistics on four long bones used in the calculation of various indices will be analysed. Comparisons between females and males, age categories, and site or regional locations will be presented to indicate intra- and inter-population variation.

6.5.1.1 Romano-British sample

Long bone lengths from Romano-British females and males were compared to one another to determine if any statistically significant differences were present. Summary statistics of humeral, radial, femoral, and tibial lengths are presented in Table 6.50. Generally, females have a smaller range in length than males. For example, the range in maximum femoral length measurements for females was 94 mm, whilst in males it was 117.50 mm. Also of interest, females and males tend to have a smaller difference in length between the minimum measurements from each long bone, whilst large differences occur between the maximum values in long bone lengths. Each group of long bones was statistically compared between females and males using *t*-tests (parametric) or Mann-Whitney tests (non-parametric). A Bonferroni-corrected alpha level was utilised to prevent Type I errors (adjusted α=0.01). All five measurements of the four long bones demonstrated statistically significant differences between Romano-British females and males ($p<0.01$) (Appendix 4, Table 1). The long bone measurement with the greatest difference between mean lengths along with the greatest statistical difference belonged to the bicondylar measurement of the femur. The disparity between the mean female and male length was over 4 cm.

Individuals who suffered from childhood stress have the possibility of presenting shortened long bones as a result of disrupted growth (Jantz and Jantz, 1999), therefore potential differences in long bone lengths within the female and male populations were also assessed in relation to skeletal indicators of poor childhood health. Further comparisons were made by ‘stress’, sex, and age categories: as stated in Chapter Five, assessing long bone lengths by age category could provide insights on the impact of childhood stress on the longevity (or frailty) of an individual. Females and males were investigated separately as significant differences in length of long bones occur between the sexes. Mean lengths of long bones within each age category are presented in Appendix 4 Figures 1-5. No statistically significant differences were found in lengths of the humerus, radius, and both measurements of the femur within female age categories (one-way ANOVAs: $p>0.05$). Within the male sample, no statistically significant differences were found occurring in long bones associated with the leg or arm (one-way ANOVAs: $p>0.05$).

Finally, long bone lengths were compared between the five sites analysed (Table 6.51). To remain consistent, females and males were analysed separately. No statistically significant differences were found between sites with regard to all long bone lengths in females (Appendix 4, Table 2). The maximum differences between mean lengths of the humerus was 10 mm (seen between Roman London and QFM) and a 5.73 mm difference was found in radial length (between the RSW and QFM). Within the male sample, no statistically significant differences were discovered in long bone lengths between the five sites (see Appendix 4, Table 2). Unlike females, males from Roman London demonstrated the shortest femoral and tibial lengths from all five sites.

Summary:

- Statistically significant differences in long bone lengths between females and males for all five measurements were found, with males demonstrating longer measurements than females.
- No statistically significant differences in each of the long bones measured were found between age categories or between different sites.

Table 6.50: *Summary statistics for Romano-British and Early Medieval measurements of four long bones (humerus, radius, femur, and tibia).*

Long Bone Measurement		Romano-British		Early Medieval	
		Female	Male	Female	Male
Humerus	N	194	263	103	136
	Min	265	282.50	273.50	298
	Max	329	362	345	373.50
	Mean	295.30	323.71	309.14	335.36
	SD	13.43	16.49	15.13	15.48
	CV	4.55	5.09	4.89	4.62
Radius	N	185	246	91	117
	Min	196	209.50	200	224.50
	Max	245	276	263	282.50
	Mean	216.44	244.84	230.43	253.00
	SD	10.79	13.33	12.97	11.89
	CV	4.99	5.44	5.63	4.70
$Femur_b$	N	234	291	132	158
	Min	366	382.50	375	398
	Max	451.50	497.50	477.50	527.50
	Mean	408.51	440.55	424.95	461.62
	SD	17.61	25.42	22.09	25.21
	CV	4.31	5.77	5.20	5.46
$Femur_m$	N	231	290	130	156
	Min	368	386.50	376.50	400.50
	Max	462	504	482	532.50
	Mean	412.94	444.01	429.22	465.26
	SD	17.87	24.94	22.14	25.42
	CV	4.33	5.62	5.16	5.46
Tibia	N	206	273	123	141
	Min	290	307	298	321
	Max	370	413	397	430
	Mean	330.27	357.71	346.08	375.70
	SD	16.75	21.92	20.15	22.20
	CV	5.07	6.13	5.82	5.91

Table 6.51: *Mean long bone lengths (mm) for Romano-British females and males at each site analysed.*

Long Bone Measurement		**Roman London** Female	Male	**RSW** Female	Male	**Butt Road** Female	Male	**Poundbury** Female	Male	**QFM** Female	Male
Humerus	N	20	45	30	49	22	46	104	109	12	14
	Mean	302.10	322.76	299.35	327.22	298.16	322.41	293.60	323.22	291.67	322.57
	SD	4.08	16.14	14.99	15.68	18.28	17.42	11.06	16.65	14.52	16.74
Radius	N	20	41	27	45	17	39	110	110	12	11
	Mean	215.05	244.40	219.61	248.09	218.53	241.71	216.14	244.65	213.88	245.45
	SD	8.27	12.00	12.36	12.17	10.00	16.35	11.39	13.57	8.50	9.55
Femur$_b$	N	30	46	33	58	36	60	124	113	12	13
	Mean	410.90	434.86	414.62	439.91	411.25	438.34	406.29	443.72	404.67	438.23
	SD	21.43	25.82	19.65	24.84	16.90	23.88	16.27	24.25	19.41	27.80
Femur$_m$	N	28	47	33	58	34	60	124	113	12	13
	Mean	414.93	438.78	418.61	443.19	416.19	442.94	410.50	447.48	408.79	441.31
	SD	20.99	26.02	19.71	25.03	16.29	23.96	16.47	24.47	20.33	28.46
Tibia	N	17	37	30	54	38	62	113	108	10	11
	Mean	331.21	351.19	336.13	359.80	334.49	358.68	328.22	357.57	328.00	360.23
	SD	18.53	20.90	19.80	19.69	18.10	23.33	15.97	21.94	16.82	21.68

6.5.1.2 Early Medieval sample

Long bone lengths for Early Medieval females and males are presented in Table 6.50. These long bone measurements were compared between females and males to determine whether any significant differences occurred. Using a Welch test, *t*-test, or Mann-Whitney test, statistically significant differences were found between females and males in each long bone measurement utilising a Bonferroni-corrected alpha level to prevent Type I errors (adjusted $\alpha=0.01$) ($p<0.0001$) (Appendix 4, Table 1). Generally, males displayed greater ranges in long bone lengths than females. Females, however, exhibit a greater range in length of the radius than their male counterparts. Similar to the Romano-British sample, a greater difference in maximum length occurred between the female and male sample than the difference between minimum lengths. This remained true for all long bone measurements except radial length, where the difference in minimum length was 24.50 mm whilst the difference in maximum length was 19.50 mm. Overall, significant differences in lengths of long bones were found between females and males within the Early Medieval sample. These five measurements were also assessed to explore possible significant differences between age categories. Mean long bone lengths for each measurement within each age category present are found in Appendix 4 Figures 1-5. Based on one-way ANOVAs, no statistically significant differences between age categories and lengths of all long bones measured occurred within the female and male categories ($p>0.05$).

Finally, long bone lengths were compared between the various regions of sites analysed within the Early Medieval sample (Appendix 4, Table 2). Once again, females and males were analysed separately as significant differences in the lengths of long bones could present false results. From the five measurements, no statistically significant differences were found between regions within the male samples in long bone measurements (one-way ANOVAs: $p>0.05$). However, females demonstrated a statistically significant difference in the bicondylar and maximum lengths of the femur (one-way ANOVA: $p=0.016$, $p=0.024$, respectively). Tukey pairwise post-hoc tests revealed these differences between regions came from females in Kent possessing longer femora than those from the Eastern region ($p=0.0030$-bicondylar, $p=0.0090$-maximum) and Apple Down ($p=0.0250$-bicondylar, $p=0.0150$-maximum).

Table 6.52: *Mean long bone lengths for Early Medieval females and males within each region analysed dating to the Early Medieval period*

Long Bone		**Oxfordshire**		**Hampshire**		**Kent**		**Eastern**		**Castledyke**		**Apple Down**	
Measurement		Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
Humerus	N	24	26	13	20	8	6	31	50	9	10	18	23
	Mean	313.69	337.08	312.35	333.33	304.13	334.42	307.73	333.69	311.94	335.00	308.58	366.00
	SD	17.72	12.74	9.71	21.90	13.01	11.21	17.74	15.34	13.06	18.29	13.91	11.64
Radius	N	22	27	9	16	8	8	27	3	6	9	19	23
	Mean	233.55	254.94	230.28	250.44	225.25	251.69	228.93	250.45	231.58	256.61	230.84	253.93
	SD	13.20	15.51	13.96	18.40	7.07	11.19	12.47	10.98	16.69	15.62	14.21	11.95
Femur$_b$	N	22	28	24	29	14	12	31	49	17	12	22	26
	Mean	426.09	466.95	425.52	462.93	440.86	460.21	416.13	454.87	426.82	459.08	420.50	469.40
	SD	18.14	24.78	18.87	30.75	25.08	13.87	20.67	23.08	27.28	15.35	3.91	26.86
Femur$_m$	N	22	28	24	27	14	12	29	48	14	13	22	26
	Mean	430.07	470.45	429.69	466.39	444.89	458.50	422.98	458.43	429.21	466.12	424.09	473.73
	SD	18.48	24.94	18.51	31.48	25.48	19.33	18.18	23.41	19.45	18.50	4.13	26.83
Tibia	N	14	27	14	23	7	9	29	44	15	15	26	24
	Mean	357.50	382.00	356.21	372.89	345.57	371.94	341.95	373.00	341.80	367.50	343.38	385.58
	SD	27.20	23.93	16.74	27.89	25.26	18.74	18.70	21.91	19.53	14.93	18.26	20.50

Females from Kent displayed longer femora with a mean difference of 20.14 mm between the mean lengths presented in Table 6.52. Females from Hampshire and Oxfordshire demonstrate longer tibiae than those previously mentioned. Specifically, Oxfordshire sites and Eastern sites display a 15.55 mm difference in mean tibial length. Overall, males from Oxfordshire and Apple Down presented the longest femora and tibiae within the entire male sample.

Summary:

- The long bone lengths for all five measurements between females and males demonstrated statistically significant differences, with males displaying longer long bone measurements
- No statistically significant differences in long bone lengths were noted between age categories or regional locations.

6.5.1.3 Comparison of long bone lengths between Romano-British and Early Medieval samples

To assess possible differences, long bone lengths from both periods were compared to one another with regard to sex, age, and site/regional locations to assess what information may be lost when using long bone lengths only to interpret temporal trends. Statistically significant differences were discovered between females in the Romano-British and Early Medieval periods with each of the five long bone measurements (Table 6.53).

Table 6.53: *Two-sample tests comparing long bone lengths between Romano-British and Early Medieval individuals. Mann-Whitney tests used for the female sample, whilst* t-*tests used for the male sample. Bonferroni-corrected α=0.0100. Statistically significant differences discovered in all comparisons.*

	Humerus	**Radius**	**Femur$_b$**	**Femur$_m$**	**Tibia**
Females	$p<0.0001$ $z=-7.28$	$p<0.0001$ $z=-7.95$	$p<0.0001$ $z=-7.33$	$p<0.0001$ $z=-7.17$	$p<0.0001$ $z=-7.32$
Males	$p<0.0001$ $t=-6.83$	$p<0.0001$ $t=-5.64$	$p<0.0001$ $t=-8.70$	$p<0.0001$ $t=-8.52$	$p<0.0001$ $t=-7.88$

Females from the Early Medieval sample had longer humeri, radii, femora, and tibiae than females from the Romano-British sample (Fig. 6.58-6.62). The difference between mean lengths of these bones ranged from 11.84 mm between the humeri to 16.44 mm between the bicondylar lengths of the femur. Males from these two samples demonstrated a similar pattern with individuals from the Early Medieval period displaying long bones that were, statistically speaking, greater in length than males from the Romano-British sample (Table 6.53) (Fig. 6.58-6.62). Considerable differences between the mean maximum length of the femur (21.25 mm) occurred between these two periods whilst, radii displayed an 8.16 mm difference between the periods. Overall, there seemed to be substantial differences in bones of the lower limb within females and males, the greatest of these differences occurring within the male sample.

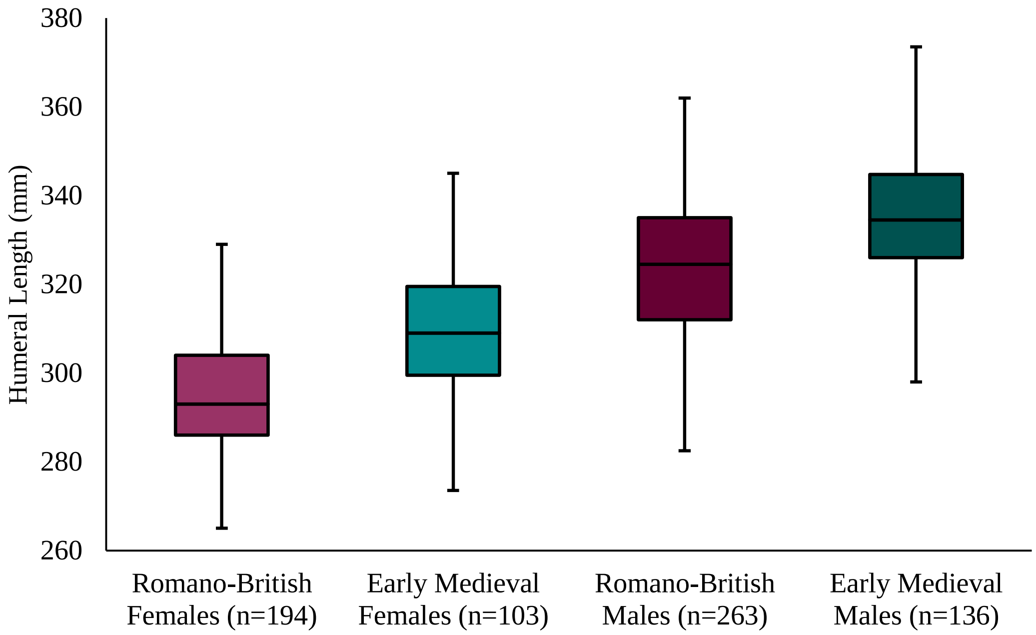


Figure 6.58.: *Box plots demonstrating humeral lengths for Romano-British and Early Medieval females and males.*

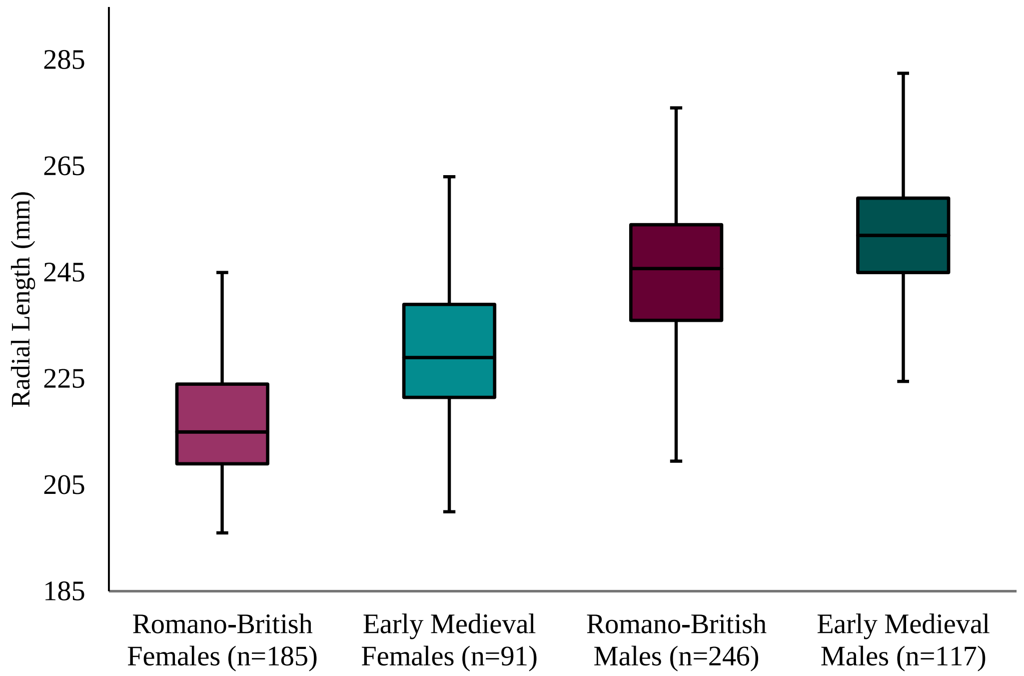


Figure 6.59: *Box plots demonstrating range in radial lengths between females and males from the Romano-British and Early Medieval samples.*

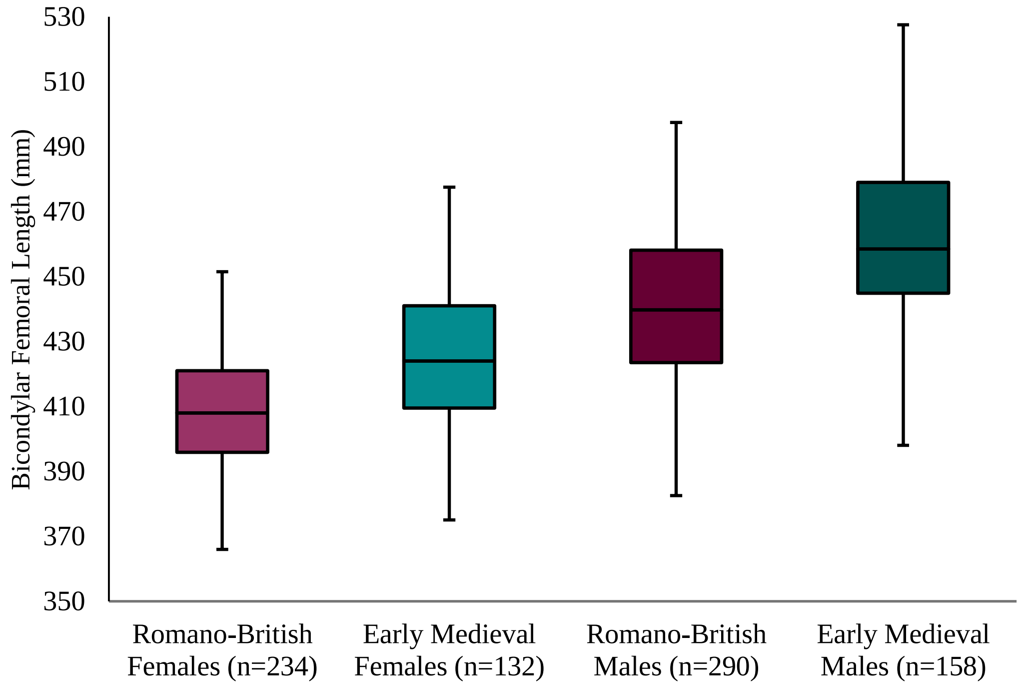


Figure 6.60: *Box plots demonstrating bicondylar lengths of femora from Romano-British and Early Medieval females and males.*

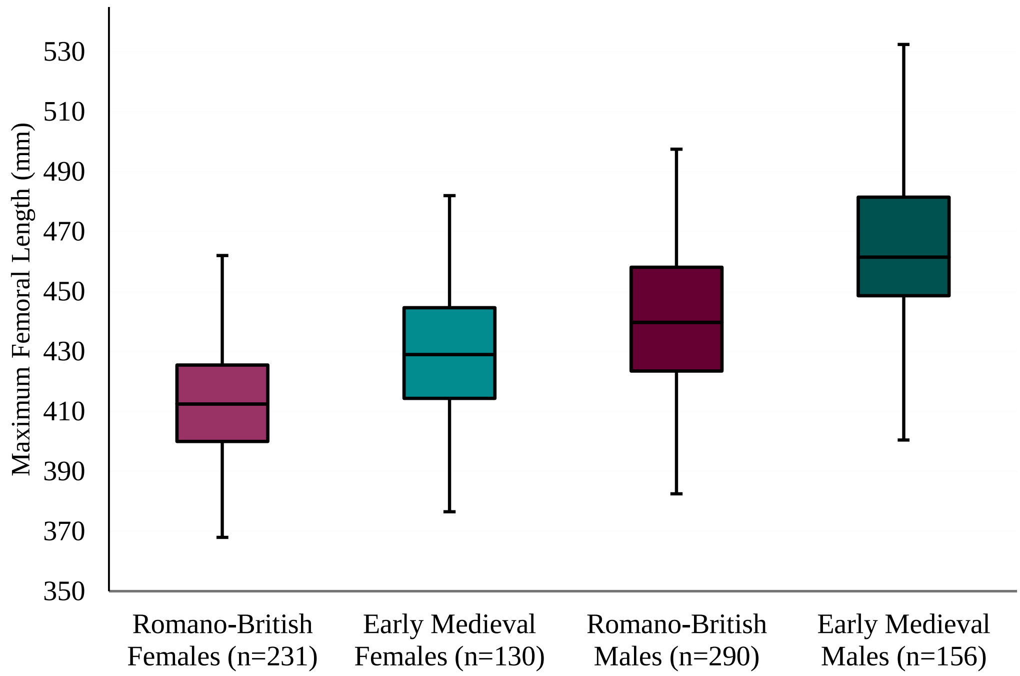


Figure 6.61: *Box plots demonstrating ranges in maximum femur lengths between females and males in both the Romano-British and Early Medieval samples.*

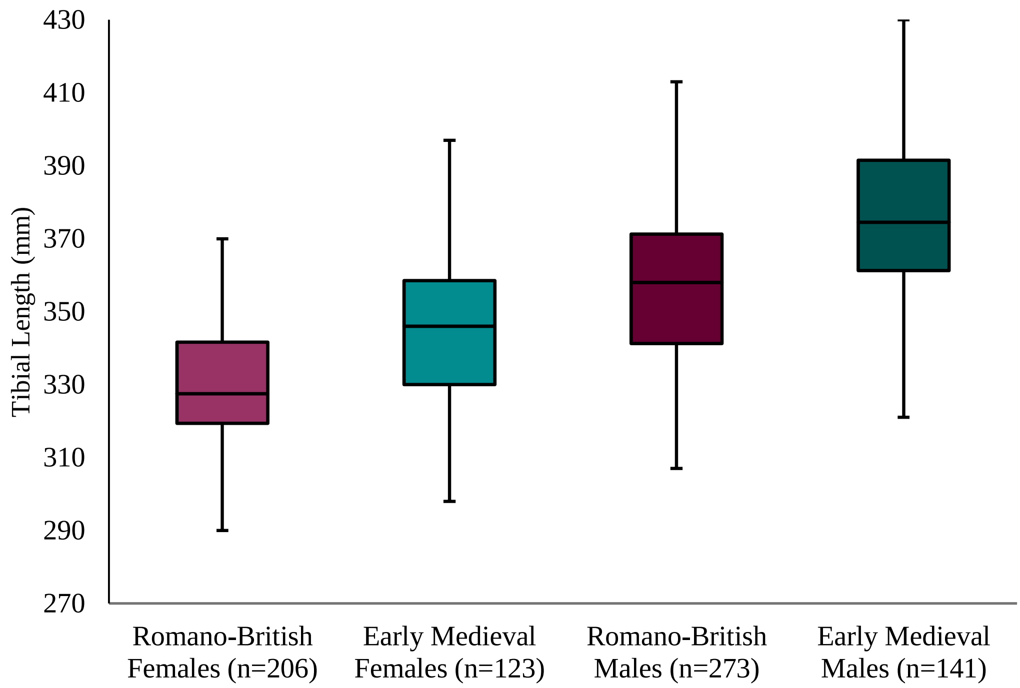


Figure 6.62: *Box plots demonstrating ranges in tibial lengths from Romano-British and Early Medieval females and males.*

Age categories were also examined to detect possible differences in growth outcomes. Within the female samples, statistically significant differences between long bone measurements remained regardless of age-at-death using one-way ANOVAs or Kruskal-Wallis for each long bone ($p<0.0001$) (see Appendix 4, Table 3 for all comparisons). Long bone lengths from males in the same age categories exhibited statistically significant differences for all long bones, however not all age categories (Appendix 4, Table 4). No statistically significant differences were detected between Romano-British and Early Medieval males in the 46+ age category for humeral, radial, and femoral lengths using a Bonferroni-corrected alpha ($\alpha=0.0033$). Radial lengths for males in the 18-25 year age category were also not statistically significant. These results signify indistinguishable mean long bone lengths within the 46+ year age category between Early Medieval and Romano-British males from the Romano-British males (i.e. only a 6.89 mm difference between the means for radial length).

Long bone lengths were finally assessed between all sites. Females and males were analysed separately. Sites demonstrating statistically significant differences will be reported. Each long bone measurement was compared between Romano-British and Early Medieval sites within the female and male samples to evaluate which sites display greatest differences in mean length. Unsurprisingly, statistically significant differences in long bone lengths occurred between periods regardless of sex (one-way ANOVAs: $p<0.0002$). Tukey post-hoc tests for all comparisons will be discussed below. Overall, males demonstrated greater differences in long bones of the lower limbs, whilst females displayed greater differences in long bones of the upper limbs.

With regard to humeral length, females from Roman London, who had the longest humeri within the Romano-British sample, had statistically indistinguishable lengths compared to Early Medieval females (based on Bonferroni-corrected Mann-Whitney post-hoc tests). Females from Poundbury and QFM demonstrated statistically significant differences between Early Medieval females from Oxfordshire, Hampshire, Castledyke, and Apple Down (Tukey post-hoc tests: $p<0.0311$). Unlike these two Romano-British sites, females from the RSW and Butt Road demonstrated humeral lengths that were indistinguishable to all Early Medieval females. Females from Kent were not only comparable to Roman London and Butt Road, but also statistically indistinguishable to females from the remaining three sites. Within the male sample, most males from these sites demonstrated statistically indistinguishable humeral lengths. Statistically significant differences occurred between males from Apple Down and males from Roman London (Tukey post-hoc: p=0.0280), Butt Road (Tukey post-hoc: p-0.0225), Poundbury (Tukey post-hoc: p=0.0374), and QFM (Tukey post-hoc: p=0.0249) with the remaining sites/regions presenting statistically indistinguishable mean lengths. Though these humeral lengths may be indistinguishable statistically, the difference between the means was almost 10 mm.

Statistically significant differences occurred within the female sample with regard to radial lengths, specifically between Roman London and the Early Medieval sites of Oxfordshire (Mann-Whitney pairwise post-hoc test: p<0.0001), Eastern (Mann-Whitney pairwise post-hoc test: p=0.0002), and Apple Down (Mann-Whitney pairwise post-hoc test: p=0.0002). Roman London was not the only site distinguishable from Oxfordshire, but the females from the remaining four Romano-British sites presented Mann-Whitney pairwise post-hoc tests with statistically different means (p<0.0010). This contrasts with the male sample, where only one site/region displayed a statistically significant difference in radial length: Castledyke vs Butt Road (Mann-Whitney pairwise post-hoc test: p=0.0279). This demonstrates that radial lengths within the male samples are indistinguishable between the periods.

A greater number of differences in lower limb lengths can be found within the male sample than the female sample. Females from Poundbury and QFM presented statistically different mean femoral lengths than those from the Early Medieval regions of Oxfordshire (p<0.0175), Hampshire (p<0.0248), Kent (p<0.0002), and Castledyke (p<0.0100) based on Tukey post-hoc tests. Those from Kent were statistically different from all remains Romano-British sites (Tukey post-hoc tests: p<0.0002). Within the male sample, differences occurred between all Romano-British sites and Early Medieval males from the Oxfordshire region (Tukey post-hoc tests: p<0.0346) and Apple Down (Tukey post-hoc tests: p<0.0103). Males from Roman London presented mean femoral lengths that were 2 cms shorter than all the Early Medieval sites; a difference that was statistically significant (Tukey post-hoc tests: p<0.0216). The only Romano-British site with indistinguishable means to the remaining Early Medieval sites/regions was Poundbury (Tukey post-hoc tests: p>0.0500). Though the femoral lengths of males from Kent display some of the shortest femora in the Early Medieval sample and are statistically different from all the Romano-British sites, the differences in length between sites was more than 1 cm.

Finally, the Early Medieval sites in the Oxfordshire region display tibial lengths statistically different to all Romano-British sites (Tukey post-hoc tests: $p<0.0284$). Females from Hampshire also present statistically longer mean tibial lengths than all Romano-British sites aside from RSW (Tukey post-hoc tests: $p<0.0234$). Overall, tibiae within the Early Medieval sample tended to be shorter, except for those females sites within Oxfordshire and Hampshire regions. Similar to the female sample, males from Oxfordshire displayed greater tibial lengths than their Roman counter-parts (Tukey post-hoc tests: $p<0.0338$). This difference in mean tibial lengths was also evident at Apple Down (Tukey post-hoc tests: $p<0.0036$). The remaining Early Medieval sites/regions, demonstrated male tibial lengths that were statistically indistinguishable to all Romano-British sites (Tukey post-hoc tests: $p>0.05$). Those from QFM displayed the longest tibial lengths from the Romano-British period, though they were shorter than males from the Early Medieval period by a mean of 15.26 mm.

This comprehensive review of long bone lengths from various sites revealed only a few significant differences between periods within the female and male samples. Though statistically significant differences in all five long bone lengths were discovered within the female and male samples between these two periods, a few sites and regions did not display this difference through time. In general, females between the Romano-British and Early Medieval periods displayed more indistinguishable mean lengths of lower limb bones than the males.

In summary:

- Females and males from sites in Oxfordshire had long bone lengths that were significantly different to many Romano-British sites with regard to lower limb lengths, however, males tended to present upper limb lengths that were indistinguishable statistically to the Romans.
- Femoral and tibial measurements of females from Eastern sites presented mean lengths that were similar to Roman females.
- Generally, females presented greater differences in mean long bone lengths in the upper limb than males, whereas differentiation between periods in the male sample occurred within the long bones of the lower limbs.

6.5.2 Body proportion indices

A total of five indices as well as relative limb and torso lengths were examined within and between the Romano-British and Early Medieval samples. These traits were compared to determine potential differences between females and males and site/regional locations. Coefficient of variations were assessed amongst females and males to determine which sex displayed greater variation. Comparisons were calculated using both parametric (independent *t*-tests, one-way ANOVA) and non-parametric (Mann-Whitney, Kruskal-Wallis) analyses to determine statistical significance. P-values for Monte Carlo (MCP) analyses will be reported when possible.

6.5.2.1 Brachial index

To calculate the brachial index, the length of the radius is divided by the length of the humerus and then multiplied by 100. Higher brachial indices tend to indicate longer radii, whilst lower brachial indices indicate shorter radii in comparison to the humerus. This subsection will present brachial indices from both Romano-British and Early Medieval samples, along with comparisons between sex and sites/regional locations.

A total of 127 Romano-British females and 190 Romano-British males had skeletal elements from the same side to calculate brachial index. Females presented a coefficient of variation (CV) of 2.93%, whilst males demonstrate greater variation with a higher CV (2.99%). Individuals from the Romano-British sample exhibited statistically significant differences in the brachial index between females and males (*t*-test-Monte Carlo permutation: $p<0.01$). Therefore, the degree of sexual dimorphism in this population is considered significant (Table 6.54).

When examining this index between age categories females demonstrated no statistically significant differences (one-way ANOVA: $p=0.13$), however those within the <18 years and 46+ years demonstrate the greatest variation from all ages (Appendix 4 Table 5). Males displayed no statistically significant differences (one-way ANOVA: $p=0.9700$). Differences in brachial indices were also analysed between sites for females and males, separately. Statistically, no significant differences were found between the five sites within the female sample (one-way ANOVA: $p=0.9700$) or within the male sample (one-way ANOVA: p=0.2000). Summary statistics between sites for females and males are presented in Appendix 4 Table 6.

Table 6.54: *Brachial index summary statistics for Romano-British and Early Medieval females and males. Shaded cells demonstrate statistically significant differences between females and males. SD=Standard Deviation*

	Romano-British Females	**Romano-British Males**	**Early Medieval Females**	**Early Medieval Males**
N	127	190	63	90
Min	68.05	70.25	69.52	71.22
Max	78.98	80.50	78.67	79.87
Mean	73.14	75.57	74.04	75.75
SD	2.14	2.24	1.97	2.07
Coefficient of Variation	2.93	2.99	2.66	2.73
Sexual Dimorphism	3.27		2.28	

Fewer individuals with both humeri and radii present were found within the Early Medieval sample. A total of 63 females and 90 males had their brachial index calculated. This index was compared between females and males to assess whether the percentage of sexual dimorphism calculated in Table 6.54 was significant. An independent *t*-test determined that statistically significant differences were present between female and male individuals with regard to their brachial index (Monte Carlo permutation: p<0.01). The coefficient of variation was slightly greater in the male population (CV=2.73%) than amongst the female population (CV=2.66%). Between age categories, no statistically significant differences occurred within either the female (one-way ANOVA: p=0.13) or male (one-way ANOVA: p=0.06) samples. Summary statistics for age categories can be found in Appendix 4 Table 5. The brachial index in females and males within the Early Medieval period were also examined between all six regional locations. Females demonstrated greater variation from sites in Oxfordshire (CV=2.88%), Hampshire (CV=1.96%), and Apple Down (CV=3.04%), with statistically significant differences occurring between various regions (Kruskal-Wallis: p=0.0254). Mann-Whitney pairwise post-hoc tests failed to identify where these differences occurred. Females from Castledyke displayed the lowest mean brachial index, whilst Oxfordshire and Apple Down displayed the highest mean brachial index. Unlike the females, males demonstrated no statistically significant difference between regions (one-way ANOVA: p=0.13). Summary statistics for all regions for females and males within the Early Medieval period can be found in Appendix 4 Table 7.

Brachial indices between the Romano-British and Early Medieval periods (Fig. 6.63) were compared to one another to detect potential differences amongst females and males, ages, and site/regional locations.

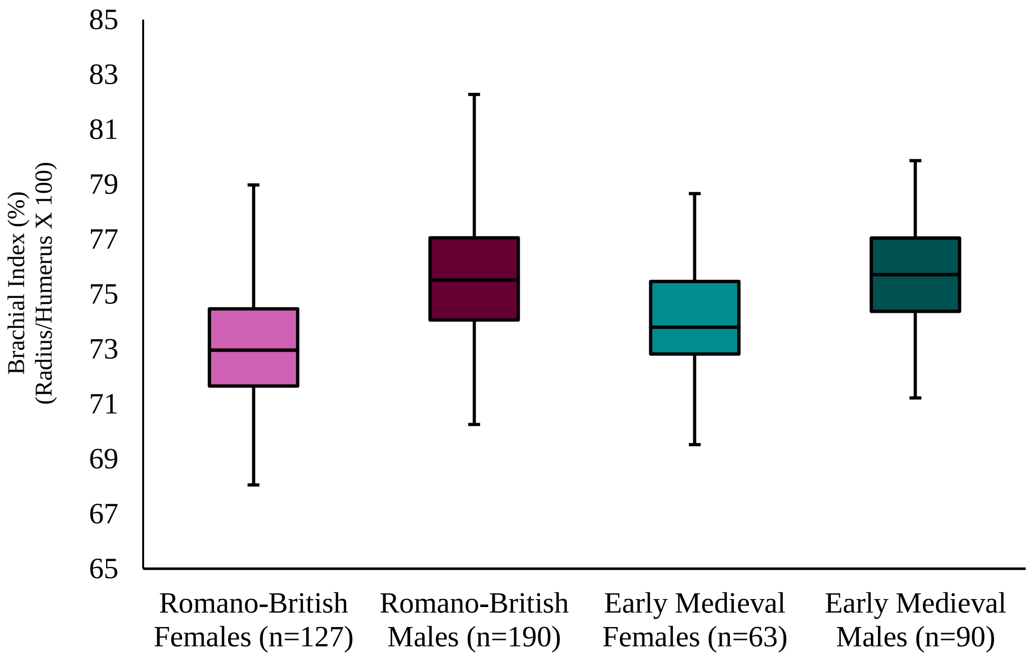


Figure 6.63: *Box and whisker plots of brachial index for Romano-British and Early Medieval females and males.*

Females from both periods were compared using an independent *t*-test and were determined to be statistically different from one another (MCP: p<0.01), with those in the Early Medieval period displaying higher values indicating elongated radii compared to humeral length. No statistically significant differences were found amongst the male sample (*t*-test-MCP: p=0.55). Greater variation was seen within the Romano-British period for both sexes (Table 6.54). Potential differences between age categories were also assessed within the female and male samples. No statistically significant differences within the female samples occurred (one-way ANOVA: p=0.13), although those from the Early Medieval period exhibit higher index values overall. Similar to the females, no statistically significant differences were discovered between male age categories (one-way ANOVA: p=0.93). Finally, all sites and regions were compared to one another to detect differences between periods with particular attention to sites and regions located within similar geographic locations. Statistically, no significant differences were found within the female sample (Kruskal-Wallis: p=0.17). Similar to the female sample, no differences were detected within the male populations (one-way ANOVA: p=0.13).

Summary:

- Statistically significant differences were present between females and males within Romano-British and Early Medieval periods. Female samples displayed a lower mean brachial index, indicating shorter radii or longer humeri than males.
- When compared, females from the Romano-British and Early Medieval periods show significant differences in brachial index, with females from the Early Medieval period demonstrating longer radii.
- When Romano-British males were assessed for differences between sites, no statistically significant differences were discovered, however males from Butt Road presented lower brachial indices than males from RSW, which demonstrated elongated radii at RSW.
- Numerous sites within similar geographic locations were determined to have significant differences in brachial index for Early Medieval females. Females from Oxfordshire sites, as well as Apple Down demonstrated higher brachial indices than females at Castledyke. Significant differences were present between Eastern sites and Oxfordshire and Castledyke, with those from Oxfordshire statistically greater in brachial index and those from Castledyke statistically lower.
- The comparison of brachial indices presented greater differences within the female samples than within the male samples.

6.5.2.2 Crural index

The crural index is an index calculated using the lengths of both the tibia and the femur. The tibial length is divided by the maximum length of the femur and multiplied by 100. As with the upper limbs, the higher the crural index, the longer the distal segment (tibia) is in relation to the proximal segment (femur). All individuals with both left or right tibiae and femora were used to calculate crural indices for the Romano-British and Early Medieval sample. Since femora and tibiae are larger long bones, they tend to survive more frequently, therefore a greater number of individuals were included in this calculation than with the brachial index (Table 6.55).

Table 6.55: *Summary statistics of crural index for Romano-British and Early Medieval females and males.*

	Romano-British Females	Romano-British Males	Early Medieval Females	Early Medieval Males
N	169	213	88	101
Min	75.13	75.06	77.14	77.11
Max	85.82	85.59	86.70	87.20
Mean	80.62	80.45	81.54	81.75
SD	2.05	2.26	2.08	2.00
Coefficient of Variation	2.54	2.81	2.55	2.45
Sexual Dimorphism	-0.21		0.26	

Unlike the brachial index, no statistically significant differences were found between Romano-British females and males (*t*-test-MCP: p=0.44). Females within this sample displayed a greater mean index than males, indicating that their tibiae were longer than males in comparison to the length of the femur. This is represented by the negative value in sexual dimorphism. Males displayed higher CV (2.81%) than females (2.54%), both of which were lower than those in the brachial index. Contrasting with differences seen within the brachial index between sites, no statistically significant differences were discovered between females (Welch *F* test of unequal variance: p=0.66) or males (one-way ANOVA: p=0.75). Summary statistics for crural index between the age categories and sites are located in Appendix 4 Tables 8 and 9.

Similar to the Romano-British sample, no statistically significant differences between females and males within the Early Medieval sample were identified (*t*-test-MCP: p=0.48). The CVs were close between females (2.55%) and males (2.45%), indicating similar variation within each group. These two groups were not sexually dimorphic with respect to this index, as indicated by the small sexual dimorphism value. Between sites, no statistically significant differences were found between females (Kruskal-Wallis: p=0.6741), but there were differences in the male sample (Kruskal-Wallis: p=0.0012). Mann-Whitney pairwise post-hoc tests with Bonferroni corrected alpha levels (α) found statistically significant differences between males at Apple Down and the following regions occurred: Oxfordshire (p=0.0002), Hampshire (p=0.0002), and Castledyke (p<0.0001); as well as males in the Eastern sites and Castledyke (p=0.0016). Males at Apple Down had higher crural indices than the majority of the sites, indicating a sample with longer tibiae in comparison to femoral length. Summary statistics for crural index within the six regions are presented in Appendix 4 Table 10.

Finally, crural indices were compared between the Romano-British and Early Medieval samples to assess possible changes through time (Fig. 6.64). Both female and male samples saw statistically significant differences in crural index between these two periods (*t*-test-MCP: p<0.01 female; p<0.01 male). Females and males from the Early Medieval period display higher crural indices than those from Roman Britain, indicating longer distal segments.

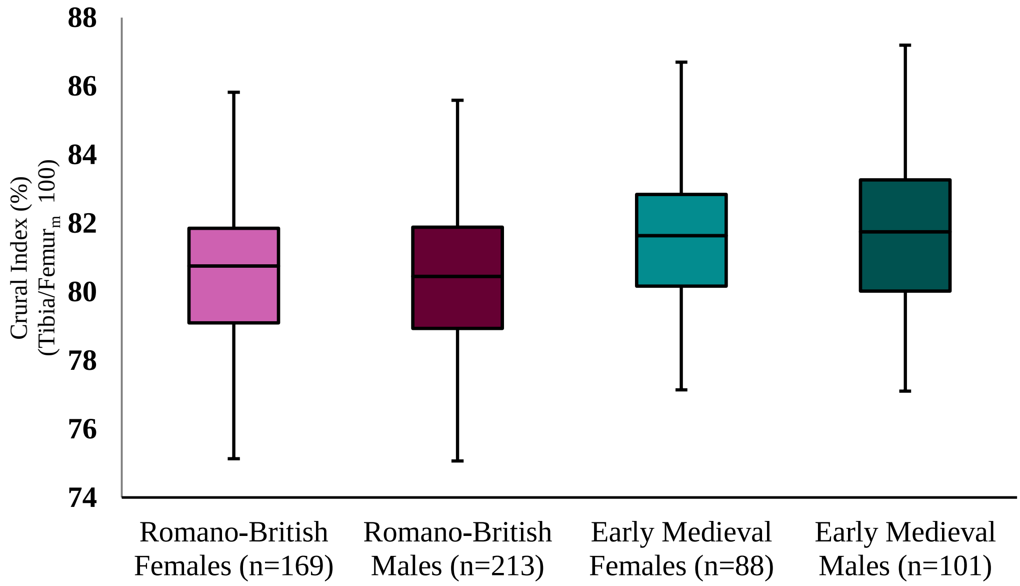


Figure 6.64: *Box and whiskers plots of the crural index for Romano-British and Early Medieval females and males.*

As for site and regions, no statistically significant differences between periods were found within the female sample (Kruskal-Wallis: p=0.36), however, statistically significant differences were found within the male sample (Welch *F* test: p<0.001). Post-hoc independent *t*-tests were utilized to examine which sites and regions were statistically different from one another. Males from Apple Down had crural indices that were statistically greater than males from all Romano-British sites except Roman London (p<0.0005), whilst those from the Eastern regions were statistically greater than males from Poundbury (*t*-test-MCP: p<0.0001) using a Bonferroni-corrected α=0.0009. In general, individuals from the Early Medieval period demonstrated higher crural indices, indicating they had longer tibiae in comparison to their femur (Fig. 6.64).

Summary:

- When crural indices were compared, no statistically significant differences between females and males occurred in either period.
- Females within the Romano-British period and females within the Early Medieval period presented no statistically significant difference in the crural index between sites. Based on this index, the ratio of tibial length to femoral length remained similar throughout their respective time periods. Females were also compared between the two periods and no statistically significant difference was present.
- A greater variation in crural indices was found in Early Medieval males between sites located within similar geographic locations. Males from Apple Down presented the greatest crural index, with males from the sites in Oxfordshire, Hampshire, Castledyke, and Eastern sites statistically smaller. Therefore, males at Apple Down demonstrate elongated tibiae. Significant differences between Eastern sites and males at Hampshire and Castledyke were revealed with males from the latter two areas demonstrating lower crural indices and therefore shortened tibiae.
- Due to the higher mean crural index of males at Apple Down, statistically significant differences between males from all five Romano-British sites occurred, with the index from Apple Down statistically higher than males from the Romano-British sample.

6.5.2.3 Intermembral index

The intermembral index is calculated from the sum of the lengths of the upper limbs (humerus and radius), divided by the sum of the lower limbs (maximum length of the femur and tibia) and multiplied by 100. With this index, the higher the value, the greater the upper limb length compared to the lower limb length. Fewer individuals had all four long bones available, thus sample sizes for this index are lower than the previous two indices. Intermembral indices for Romano-British and Early Medieval females and males are found in Table 6.56.

Table 6.56: *Summary statistics of intermembral index for Romano-British and Early Medieval females and males. Shaded cells represent statistically significant differences between females and males.*

	Romano-British Females	**Romano-British Males**	**Early Medieval Females**	**Early Medieval Males**
N	97	113	36	54
Min	63.87	65.59	67.29	66.23
Max	74.53	75.87	75.98	74.55
Mean	69.37	70.91	69.76	70.38
SD	2.07	2.07	1.88	1.66
Coefficient of Variation	2.99	2.92	2.69	2.36
Sexual Dimorphism	2.20		0.88	

Within the Romano-British sample, a statistically significant difference between females and males was discovered (*t*-test-MCP: p<0.01), therefore this index was considered sexually dimorphic. Males exhibited greater upper limb lengths when compared to lower limb lengths than the female sample, whilst females displayed slightly greater variation (CV=2.99%) than males (CV=2.92%). When assessed between the five archaeological sites, no statistically significant differences occurred within the female (one-way ANOVA: p=0.35) or male (one-way ANOVA: p=0.27) samples. Summary statistics for site categories are located in Appendix 4, Table 12.

No sexual dimorphism in this index was observed in Early Medieval females and males (*t*-test-MCP: p=0.05). Females dating to the Early Medieval period had slightly shorter upper limbs compared to lower limbs than males, though this difference was not sexually dimorphic (Table 6.56). Greater variation was demonstrated within the female sample with greater coefficient of variation (CV=2.69%) than males (CV=2.36%). Between the six regions, no statistically significant differences occurred between females (one-way ANOVA: p=0.47), though the same could not be said for the males (one-way ANOVA: p<0.01). Tukey post-hoc tests found statistically significant differences in male intermembral index between Castledyke and Oxfordshire (p=0.04), Hampshire (p<0.01), Apple Down (p<0.01), and Eastern regions (p=0.02). Males from Castledyke exhibited the highest mean index (72.83), with a greater sum in upper limbs compared to lower limb lengths. Summary statistics for regions within the female and male samples can be found in Appendix 4 Table 13.

Finally, the intermembral index was compared between the Romano-British and Early Medieval periods (Fig. 6.65). No statistically significant differences were uncovered between the female (Mann-Whitney-MCP: p=0.51) or male samples (*t*-test-MCP: p=0.10). Within the female sample, those from the Early Medieval period tended to have slightly higher indices than females from Roman Britain. The inverse was true for males, where Romano-British males exhibited the highest mean index. Intermembral indices were finally compared between all sites for both female and male samples.

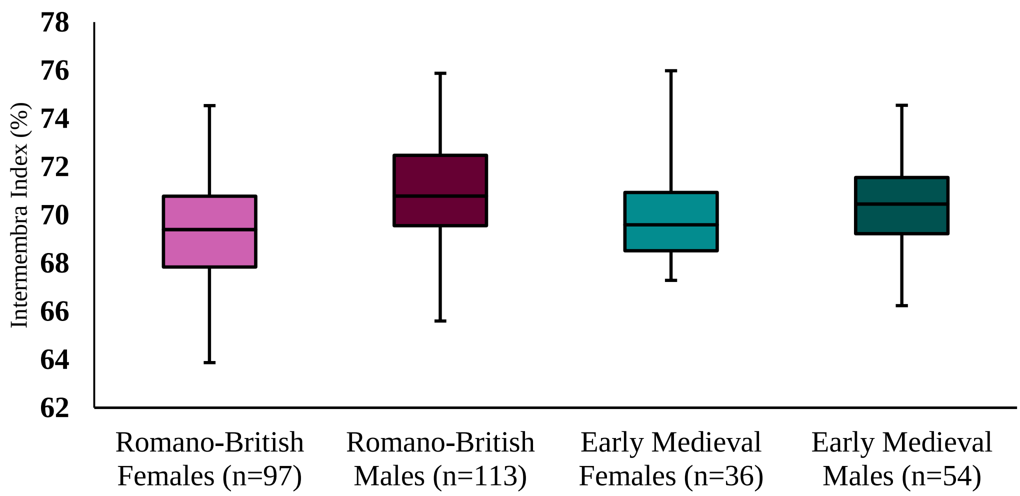


Figure 6.65: *Box and whiskers plot of intermembral index for Romano-British and Early Medieval females and males.*

No statistically significant differences between females from various geographic locations were found (one-way ANOVA: p=0.49). Based on a one-way ANOVA, statistically significant differences occurred within the male sample (p=0.03). Tukey post-hoc tests found this difference between the Romano-British site of QFM and the Early Medieval site of Castledyke (p<0.01), of which the latter displayed greater upper limb lengths in comparison to lower limb lengths.

Summary:

- Comparisons between females and males with regard to the intermembral index discovered only those in the Romano-British sample present statistically significant differences. Females in the Romano-British sample display shortened upper limbs when compared to lower limb lengths whereas Romano-British males demonstrate longest upper limbs in comparison to lower limb length. Early Medieval females and males did not present such differences.
- Females within each period were statistically compared to one another by sites and no differences in the intermembral index was found. Similarly, when all females from each site were compared, no differences in female proportions were present.
- Romano-British males from Roman London and QFM presented statistically significant differences in intermembral index, with males from the latter displaying shorter upper limbs in comparison to lower limb length. The intermembral index of males from Roman London is highest in the sample and more similar to indices found in the Early Medieval period.
- Within the male sample from the Early Medieval period, statistically significant differences between Castledyke and four other sites (Oxfordshire, Hampshire, Eastern, and Apple Down) occurred. These four sites displayed shorter upper limbs in comparison to lower limb length when compared to Castledyke.
- The greatest difference in the intermembral index occurs in the male samples of Castledyke and QFM, the latter of which presents the lowest index and the former presents the highest index from all samples.

6.5.2.4 Humerofemoral index

The humerofemoral index compares the length of the humerus to the maximum length of the femur. It is calculated by dividing the length of the humerus by the maximum length of the femur and multiplying by 100. As with other indices, the higher the index, the greater the humeral length is in comparison to the maximum length of the femur. Due to the higher probability of recovering the larger long bones such as the femur and the humerus, a greater number of individuals were able to have their humerofemoral index calculated (Table 6.57).

Table 6.57: *Summary statistics of humerofemoral index for Romano-British and Early Medieval females and males. Shaded cells represent statistically significant differences between females and males.*

	Romano-British Females	**Romano-British Males**	**Early Medieval Females**	**Early Medieval Males**
N	141	192	74	97
Min	66.51	67.98	66.95	68.67
Max	77.91	77.80	78.09	76.79
Mean	72.23	72.69	72.59	72.67
SD	2.23	2.14	2.48	2.56
Coefficient of Variation	3.08	2.94	3.41	2.20
Sexual Dimorphism	0.63		0.11	

Romano-British females and males demonstrated no statistically significant differences in humerofemoral indices when compared to one another using an independent *t*-test (MCP: p=0.08). Therefore, the lengths of the humerus compared to the femur were not considered to be sexually dimorphic despite males exhibiting longer long bone lengths overall. Females displayed greater variance than males with this index (CV=3.08% vs CV=2.94%). No statistically significant differences were found between the five sites with regard to female (one-way ANOVA: p=0.42) and male (one-way ANOVA: p=0.05) humerofemoral indices. Both sexes from QFM displayed the lowest indices, indicating slightly shorter humeri or longer femora, whilst those from

Roman London displayed the highest indices. Summary statistics for female and male age categories and sites can be found in Appendix 4 Tables 14 and 15.

Similar to Romano-British females and males, no statistically significant differences were found with regard to humerofemoral index between Early Medieval females and males (*t*-test for unequal variation: p=0.79). The small value in sexual dimorphism reflected the similarities in the index between females and males. Greater variation was seen within the female sample (CV=3.41%) than the male sample (CV=2.20%). Males exhibited only a slightly higher index than females (Table 6.57), despite possessing greater lengths in long bones. No statistically significant differences were discovered between males and all six sites using Welch *F* test (p=0.23). Generally, males from Castledyke and Kent presented the highest humerofemoral index with humeri that were greater in length in comparison to femoral length. Summary statistics for Early Medieval age categories and regions can be found in Appendix 4 Tables 14 and 16.

When compared between the Romano-British and Early Medieval samples, no statistically significant differences were detected between females (*t*-test-MCP: p=0.29) and males (Welch test: p=0.9276) with regard to humerofemoral index. Romano-British males presented the highest values for this index, followed by Early Medieval males, Early Medieval females, and finally Romano-British females (Fig. 6.66).

Finally, sites and regions were compared to one another for females (one-way ANOVA: p=0.39) and males (Kruskal-Wallis: p=0.30). Males from QFM presented lower humerofemoral index values, indicating shorter humeral length in comparison to maximum femoral length. In general, Early Medieval regions tended to display greater humerofemoral indices than the Romano-British sample.

Summary:

- There were no statistically significant differences between females and males within the Romano-British or Early Medieval samples with regard to the humerofemoral index.
- Within the Romano-British sample, no differences in the length of the humerus in comparison to the length of the femur were present between sites for either females or males. The highest index came

from females and males from Roman London and the lowest came from QFM.

- Within the female sample, females from Castledyke demonstrated longer humeri. Males from Oxfordshire, Kent, Eastern Sites and Castledyke presented higher indices than QFM.

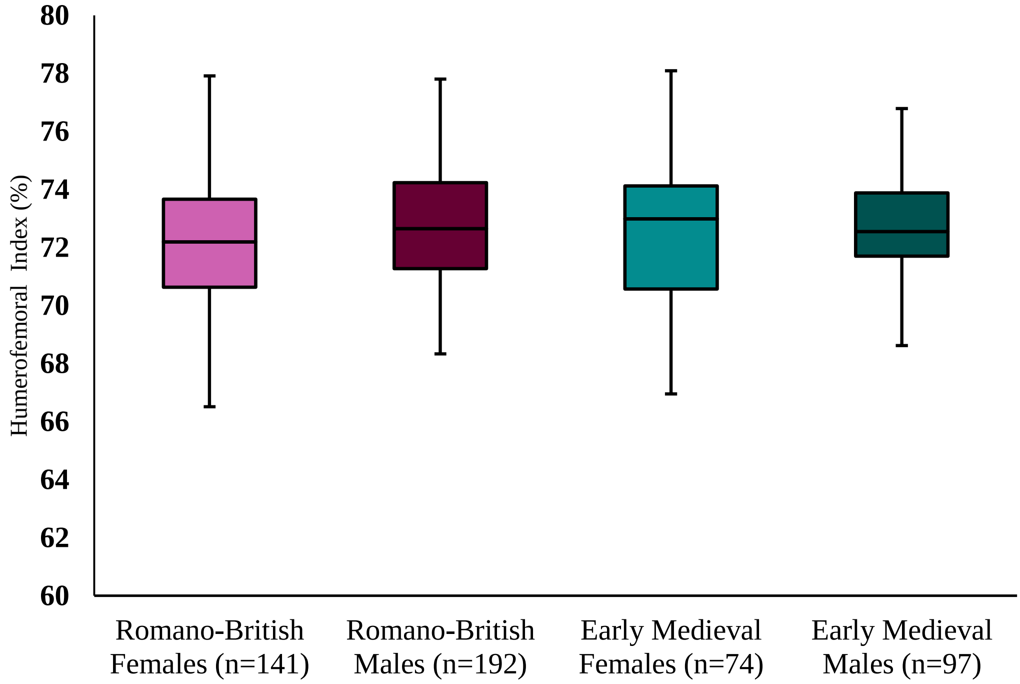


Figure 6.66: *Box and whiskers plot of humerofemoral index for Romano-British and Early Medieval females and males.*

6.5.2.5 Brachiocrural index

The brachiocrural index describes the length of the radius in comparison to the length of the tibia. It is calculated by dividing the length of the radius by the length of the tibia and multiplied by 100. The total number of individuals from the Romano-British and Early Medieval samples with both the radius and tibia present are shown in Table 6.58.

Statistically significant differences between Romano-British females and males were present when the brachiocrural index was tested using independent *t*-test for unequal variance ($p<0.01$), therefore, this index was considered to be sexually dimorphic (Table 6.58). The variation seen between both females (CV=3.85%) and males (CV=3.18%) was much higher than any of the previous indices examined. Males displayed a greater mean brachiocrural index (68.39) than females (65.35), indicating longer radii or shorter tibiae than females.

Table 6.58: *Summary statistics of brachiocrural index for Romano-British and Early Medieval females and males. Shaded cells represent statistically significant differences between females and males.*

	Romano-British Females	**Romano-British Males**	**Early Medieval Females**	**Early Medieval Males**
N	133	165	52	77
Min	59.42	63.61	61.31	61.23
Max	71.43	74.13	71.13	72.51
Mean	65.35	68.39	66.00	67.25
SD	2.52	2.12	2.36	2.41
Coefficient of Variation	3.85	3.18	3.57	3.58
Sexual Dimorphism	4.55		1.88	

Finally, the five archaeological sites were examined for potential differences between sites within the female and male samples. No statistically significant differences were found within the female (Welch *F* test: p=0.68) or the male (one-way ANOVA: p=0.10) samples. The female sample with the greatest brachiocrural index was QFM, whilst males from Poundbury present the highest index for males. Summary statistics for sites can be found in Appendix 4 Table 18.

Like those in the Romano-British sample, females and males from the Early Medieval period displayed statistically significant differences in the brachiocrural index (*t*-test-MCP: p<0.01). Due to the statistically significant difference between females and males, this index was considered to be sexually dimorphic (Table 6.58). The amount of variation within both groups was similar with males exhibiting a CV of 3.58% whilst females had a CV of 3.57%. When lengths of the radius compared to the tibia were compared across the six regions for both females and males, no statistically significant differences occurred (one-way ANOVAs: p=0.19-females; p=0.20-males).

Females from the Oxfordshire and Kent sites present the highest indices within the female sample, whilst males from the Castledyke and Oxfordshire sites represent the highest indices in the male sample. Interestingly, the Castledyke females have the lowest brachiocrural index (64.66), whilst the males present the highest brachiocrural index (69.27), leaving this site with the highest sexual dimorphism of the six regions. Summary statistics for sites with regard to the brachiocrural index of females and males from the Early Medieval period can be found in Appendix 4 Table 19.

Brachiocrural indices for Romano-British and Early Medieval females and males were compared to detect differences in the length of the radius in comparison to the length of the tibia through time (Fig. 6.67). For females belonging to these two periods, no statistically significant difference with regard to this body proportion was discovered (*t*-test-MCP: p=0.11), with females from the Early Medieval period displaying a slightly elongated radii than females from the Romano-British period.

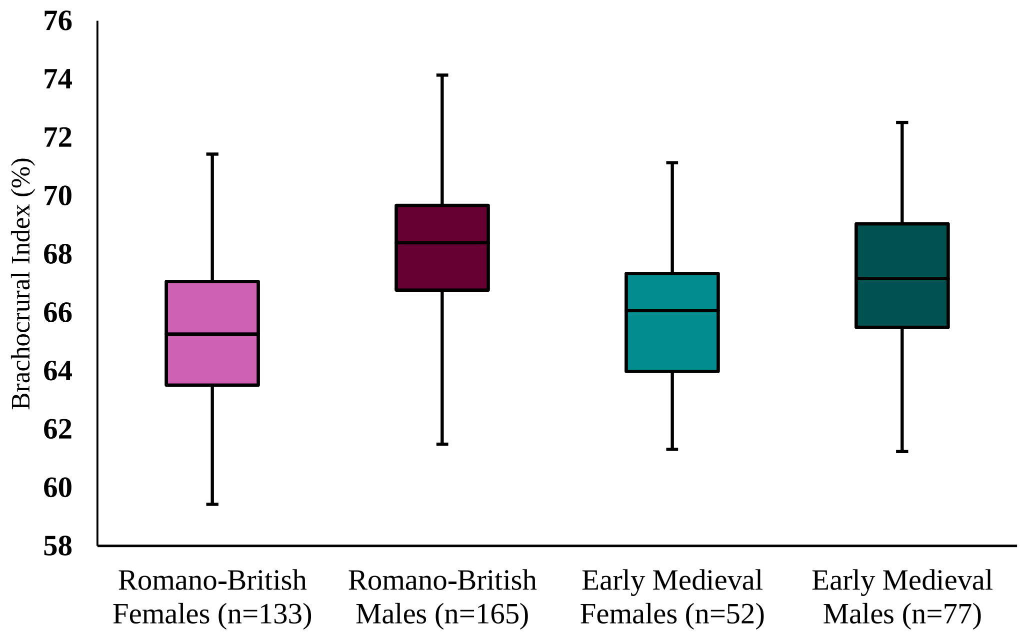


Figure 6.67: *Box and whiskers plot of brachiocrural index for Romano-British and Early Medieval females and males.*

Within the male samples, statistically significant differences were present between the two periods (*t*-test-MCP: $p<0.01$). Males from the Romano-British period demonstrated a higher mean brachiocrural index (68.39) than males from the Early Medieval period (67.25). The smaller index in Early Medieval males is due to longer tibiae (mean of 376 mm) compared to Romano-British males (mean of 358 mm). Finally Romano-British sites were compared to Early Medieval sites within similar geographic regions to detect differences in geographic locations between time periods. Females demonstrated no statistically significant differences in brachiocrural indices (one-way ANOVA: $p=0.29$). Unlike the female sample, the male sample exhibited statistically significant differences between sites (one-way ANOVA: $p<0.01$), however Tukey post-hoc tests failed to discover where this occurred. Though many of the Romano-British sites were statistically higher in the brachiocrural index than Early Medieval sites, two sites within the Early Medieval period displayed indices that were higher than those in Roman Britain: Castledyke and Kent.

Summary:

- When the braciocrural index was compared between females and males within their respective periods, statistically significant difference were present. Females from the Romano-British and Early Medieval periods demonstrated lower brachiocrural indices than their male counterparts. This could indicate either shortened radii or elongated tibiae.
- The brachiocrural index was compared between periods for females and males, with significant differences occurring only within the male samples. Males from the Romano-British sample present higher indices than Early Medieval males. Due to the significantly longer tibiae in the Early Medieval male sample, it is proposed that these lower values in the Early Medieval period are due to elongated tibiae and not shortened radii.
- Comparisons of sites within the Romano-British and Early Medieval periods revealed significant differences in brachiocrural indices within the female and male samples. Females from Oxfordshire presented a significantly higher index than females from Poundbury and Butt Road indicating elongated radii in comparison to tibial length. Within the male sample, statistically significant differences between the following sites occurred: RSW and Poundbury vs Oxfordshire, Hampshire, Apple Down, and Eastern sites; and Roman London vs Apple Down. Males from Romano-British sites displayed higher indices likely indicating shortened tibiae in comparison to radial length.

6.5.2.6 Skeletal torso height

The skeletal torso height represents the trunk height and is calculated by adding the vertebral body heights of the first thoracic through to fifth lumbar measurements. Lower values represent shorter torso length, whilst higher values equate to longer torso lengths. The total number of Romano-British and Early Medieval females and males that had measurable and estimated vertebrae are presented in Table 6.59. A total of 87 Romano-British females and 107 males were assessed for significant differences with regard to skeletal torso height. Based on a two-sample *t*-test, statistically significant differences between the sexes were present (MCP: $p<0.01$). Due to this significance, skeletal torso height is considered to be a sexually dimorphic measurement. Each site was examined to determine if significant differences arose in skeletal torso height. Surprisingly, no statistically significant differences in skeletal torso height between females and males with a Bonferroni-corrected alpha ($\alpha=0.0100$). Summary statistics for skeletal trunk height for females and males within each site can be found in Appendix 4 Table 21.

Table 6.59: *Summary statistics of skeletal torso height (ΣT1-L5) for Romano-British and Early Medieval females and males. Shaded cells represent statistically significant differences between females and males.*

	Romano-British Females	**Romano-British Males**	**Early Medieval Females**	**Early Medieval Males**
N	87	107	48	55
Min	332.67	332.45	331.42	336.87
Max	405.48	428.80	385.42	430.66
Mean	365.90	377.14	357.46	386.69
SD	17.53	17.58	12.14	21.05
Coefficient of Variation	4.79	4.66	3.40	5.44
Sexual Dimorphism	2.76		7.86	

Females and males within the Early Medieval period demonstrated similar findings as those within the Romano-British sample. A smaller sample was available for comparison in the Early Medieval period, with only 48 females and 55 males with skeletal elements necessary to calculate skeletal trunk height. When compared, a statistically significant difference was present between females and males within this sample (t-test for unequal variance: $p<0.01$). Similar to the Romano-British sample, skeletal trunk height was considered a sexually dimorphic trait due to the statistically significant difference between females and males. Of the six regions comprised of multiple sites, statistically significant differences in female and male skeletal trunk height were present at Oxfordshire (t-test: $p=0.0003$) and Hampshire (t-test: $p=0.0014$) only with a Bonferroni-corrected $\alpha=0.0083$. Summary statistics for Early Medieval females and males from each of the six regions can be found in Appendix 4 Table 22.

Finally, skeletal trunk height from these samples were compared between the Romano-British and Early Medieval periods (Fig. 6.68). Within the female samples, statistically significant differences in skeletal trunk height between the two periods was present (t-test unequal variance: $p<0.01$).

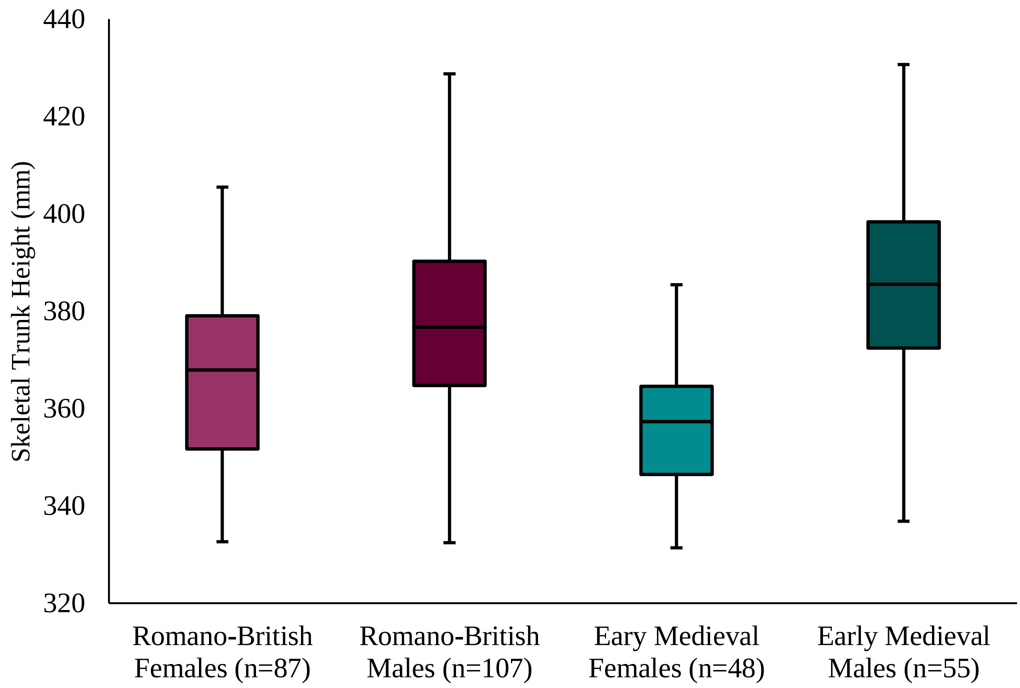


Figure 6.68: *Box and whisker plots of skeletal trunk height for Romano-British and Early Medieval females and males.*

Females from the Romano-British period displayed greater torso height than females from the Early Medieval period. When females from all sites from both periods were compared to one another, no statistically significant difference arose (Kruskal-

Wallis: p=0.16). Within the male samples, a statistically significant difference between all sites was found (one-way ANOVA: p=0.03). Interestingly, the Tukey pairwise post-hoc test failed to discovere where these differences between the Romano-British and Early Medieval sites occurred.

Summary:

- A statistically significant difference between females and males was present within both the Romano-British and Early Medieval samples. Males from both periods presented skeletal torso heights that were significantly longer than females.
- Females and males from both periods were compared to one another to determine if differences in skeletal torso height between periods was present. Significant differences between both females and males through time were found, with Romano-British females presenting longer torsos than Early Medieval females and Romano-British males displaying shorter torso height than Early Medieval males.
- Overall, no differences between females at different sites were found. Generally, females from the Romano-British sites were significant longer in the torso than their Early Medieval counterparts. This result highlights the important role of the torso when assessing stature. Calculating stature from long bone lengths will suggest that Early Medieval females are significantly taller than Romano-British females, however, when body proportions are considered, this difference disappears due to changes in torso lengths between the two periods.
- Statistically significant differences in skeletal torso height were present between males from all sites between the periods, though it could not be determined where these occurred.

6.5.2.7 Relative lower limb length/estimated stature

Relative lower limb lengths assesses the length of the lower limbs in comparison to total estimated stature. It is calculated by dividing the sum of the maximum length of the femur and tibia by the estimated stature and multiplying by 100. Lower values in relative lower limb length indicate smaller lower limb length when compared to total stature. Higher values could indicate longer femoral or tibial lengths in comparison with total stature. The number of individuals with skeletal elements present to calculate the relative lower limb length were higher than the previous two indices (humerofemoral and brachiocrural) as long bones from the lower limbs tend to be recovered more frequently. Within the Romano-British sample, a total of 174 females and 212 males had the relative lower limb length calculated (Table 6.60). A statistically significant difference was present between females and males with regard to relative lower limb length (*t*-test with unequal variance: $p<0.01$).

Table 6.60: *Summary statistics of the relative lower limb length for Romano-British and Early Medieval females and males. Shaded cells represent statistically significant differences between females and males.*

	Romano-British Females	**Romano-British Males**	**Early Medieval Females**	**Early Medieval Males**
N	174	212	88	102
Min	45.84	45.97	47.41	47.43
Max	50.62	51.28	52.46	51.62
Mean	48.13	48.69	49.69	49.68
SD	0.98	1.08	1.11	0.84
Coefficient of Variation	2.04	2.22	2.23	1.69
Sexual Dimorphism	1.16		-0.02	

Despite the lower value given for sexual dimorphism and the similar mean relative lower limb length within the Romano-British sample, the comparison of lower limb lengths to stature is considered sexually dimorphic (Table 6.66). Overall, males displayed greater variation (CV=2.22%) compared to the females (CV=2.04%). When females and males from the five sites analysed were compared to one another no statistically significant differences between sites within female (one-way ANOVA: $p=0.16$) and male (Kruskal-Wallis: $p=0.27$) samples occurred. Females from Poundbury demonstrated the smallest relative lower limb length indicating shorter lower limbs, whilst males from QFM displayed the highest index, indicating elongated lower limbs in comparison to final stature. Summary statistics on sites for both females and males can be found in Appendix 4 Table 24.

Unlike individuals recovered from Romano-British archaeological sites, differences between the 88 females and 102 males from Early Medieval sites were determined to be statistically insignificant (*t*-test-MCP: p=0.34) (Table 6.60). Although the female mean (49.69) was slightly higher with a greater variation (CV=1.11%) than the male mean (49.68) and variation (CV=0.98%), relative lower limb lengths were not considered to be a sexually dimorphic index. Finally, sites within similar geographic regions were assessed for possible differences between females and males. Statistically, no significant differences were found between any of the sites within the female (one-way ANOVA: p=0.46) or male (one-way ANOVA: p=0.70) samples. Females with the highest mean relative lower limb length came from the Kent region, whilst males from Apple Down exhibited the highest mean relative lower limb length. In all sites except for Apple Down, females had larger index values, indicating they had slightly longer lower limbs in comparison to stature or slightly shorter torsos. Summary statistics for sites in both female and male samples can be found in Appendix 4 Table 25.

Finally, the relative lower limb length index was compared between the two time periods to assess potential differences from these two samples (Fig. 6.69). Females from both periods exhibited statistically significant differences in this index (*t*-test-MCP: p<0.01) with those from the Early Medieval period displaying higher index values indicating longer lower limbs in comparison to final stature. As for the male samples, statistically significant differences were discovered (*t*-test for unequal variance: p<0.01) with males from the Romano-British period showing shorter lower limb lengths in comparison to males from the Early Medieval period.

Overall, statistically significant differences between these two periods within female (one-way ANOVA: p<0.01) and male (Kruskal-Wallis: p<0.01) sites were uncovered, with those from the Early Medieval period displaying greater indices. Tukey pairwise post-hoc tests from the female sample found statistically significant differences between four of the five Romano-British sites and four of the six Early Medieval sites.

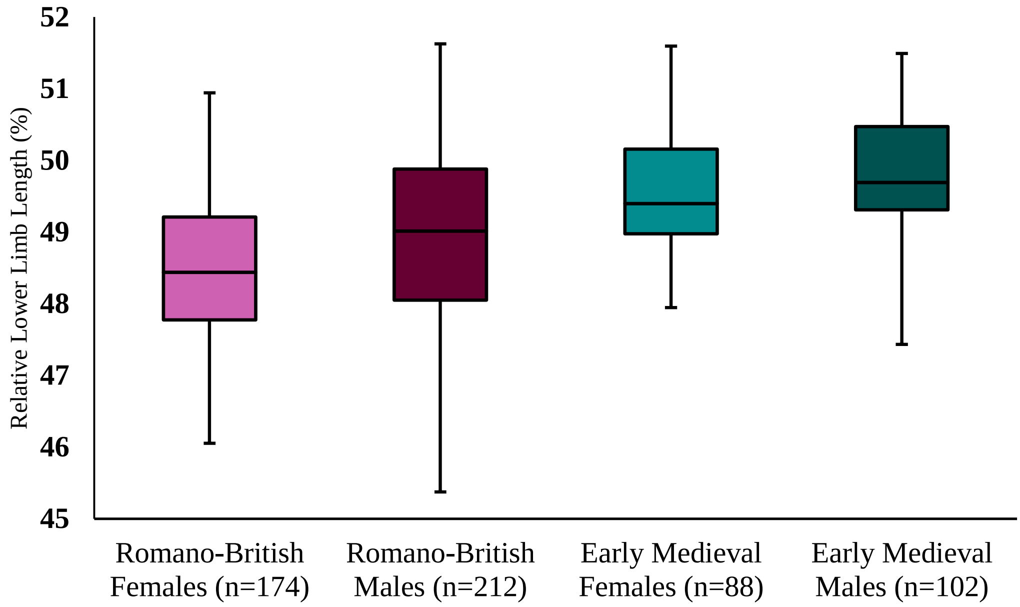


Figure 6.69: *Box and whiskers plots of relative lower limb length for Romano-British and Early Medieval females and males.*

These differences occurred between Roman London, Poundbury, and QFM and the four regions of Oxfordshire, Hampshire, Kent, and Castledyke ($p<0.05$). The remaining Romano-British site of Butt Road was determined to be statistically different from Kent only ($p=0.032$). Mann-Whitney pairwise post-hoc tests for the male samples discovered statistically significant differences between the Romano-British sites of Roman London and Oxfordshire ($p=0.0002$), Eastern ($p=0.0002$) and Apple Down ($p<0.0001$), as well as between Butt Road and Apple Down ($p=0.0005$) with Bonferroni-corrected $\alpha=0.0010$. Once again, males from the Early Medieval regions display elongated lower limbs in comparison to final stature.

Summary:

- Females and males were compared to one another in each period and statistically significant differences in the lower limb length between the sexes were only present within the Romano-British sample. Males displayed longer lower limbs in comparison to total stature than females.
- Although no statistically significant differences were present within female and males samples between sites in their respective periods, statistically significant differences between periods occurred. Overall, individuals from the Early Medieval period displayed significantly longer lower limb lengths at several sites than those from the Romano-

British period. Specifically, both females and males from Roman London and Poundbury demonstrated shorter lower limb lengths in comparison to females and males from Oxfordshire and Hampshire. Males from Apple Down had longer lower limb lengths relative to total stature in comparison to Roman London and Butt Road.

6.5.2.8 Relative upper limb length/torso height

Relative upper limb length/torso height calculates the length of upper limbs in comparison to torso length, allowing researchers to examine proportions of these appendages with the axial portion of the body. To calculate relative upper limb length/torso height, the summed total of the humerus and radius are divided by the summed heights of the first thoracic through the fifth lumbar body multiplied by 100. Higher values of relative upper limb lengths indicate elongated upper limbs in comparison to torso height, whilst lower values represent shortened upper limbs. The difficulty in assessing this index was finding individuals with all thoracic and lumbar vertebrae present as well as both the humerus and radius. Due to the large number of skeletal elements required to calculate relative upper limb length, sample sizes from both the Romano-British and Early Medieval periods are small.

Within the Romano-British sample, a total of 36 females and 49 males had the relevant skeletal elements present. Females and males were compared and statistically significant differences were uncovered between the two sexes (*t*-test-MCP: $p<0.01$). The high value given for sexual dimorphism and the statistically significant difference between females and males indicate that this comparison was sexually dimorphic (Table 6.61). Altogether, males exhibit higher values of relative upper limb/torso height, indicating greater length of the upper limbs in comparison to torso height than their female counterparts. A greater amount of variation was detected within the female sample with CV=5.54%, whilst males demonstrated more tightly clustered values (CV=4.97%). These CV percentages are among the highest of the body proportions calculated, representing greater variation within these two groups. Between the five sites, no statistically significant differences among females (one-way ANOVA: $p=0.20$) and males (one-way ANOVA: $p=0.75$) were present. The site with the greatest variation in relative upper limb lengths/torso height for both female and male samples was Butt Road (CV=5.76%, CV=9.28%, respectively). Summary statistics for sites within female and male samples are found in Appendix 4 Table 27.

Table 6.61: *Summary statistics of the relative upper limb length vs torso height for Romano-British and Early Medieval females and males. Shaded cells represent statistically significant differences between females and males.*

	Romano-British Females	Romano-British Males	Early Medieval Females	Early Medieval Males
N	36	49	29	40
Min	124.82	136.18	136.07	141.07
Max	152.55	169.91	171.75	172.72
Mean	140.06	151.74	152.01	152.52
SD	7.74	7.54	8.71	6.48
Coefficient of Variation	5.52	4.97	5.73	4.25
Sexual Dimorphism	8.01		0.33	

A total of 29 females and 40 males from the Early Medieval period had their relative upper limb length/torso height calculated. Individuals from the Early Medieval period contrast with those from the Romano-British period as no statistically significant differences were found between the female and male samples (*t*-test-MCP: p=0.78). The lower sexual dimorphism value along with the insignificant difference between females and males (0.51 difference) helped in the determination that the relative upper limb length/torso height ratio is not a sexually dimorphic trait in the Early Medieval sample (Table 6.61). Variation of this ratio was among the greatest of all body proportions for both females (CV=5.73%) and males (CV=4.25%). Sites were compared within the female and male samples. In general, the ratio of relative upper limb length/torso height was fairly homogeneous amongst all sites. Statistically, no significant differences were found within female (Kruskal-Wallis: p=0.86) or male (one-way ANOVA: p=0.42) samples. Females and males from the Kent region displayed the lowest means (147.93 mm and 141.07 mm, respectively); however, the sample was miniscule and therefore not reliable. Overall, females in five of the six regions exhibit elongated upper limb length as demonstrated by higher ratios than males. The exception was Apple Down. Summary statistics of female and males for regions are located in Appendix 4 Table 28.

Finally, relative upper limb lengths/torso heights were compared amongst females and males between the Romano-British and Early Medieval samples (Fig. 6.70). Within the female sample, statistically significant differences were uncovered (*t*-test-MCP: p<0.01), with those in the Early Medieval period demonstrating longer upper limbs with higher values.

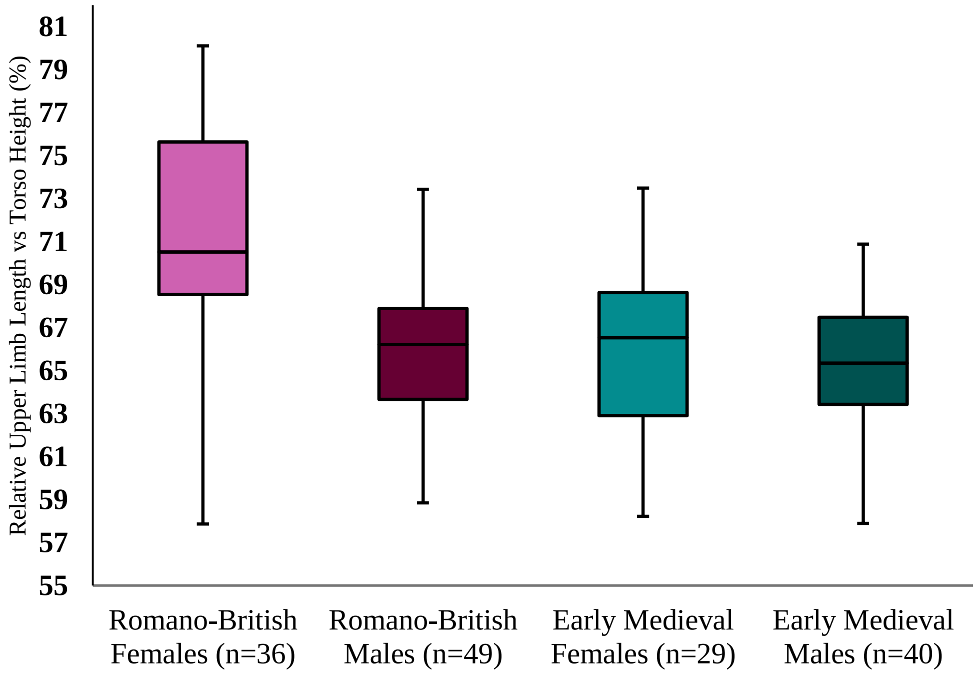


Figure 6.70: *Box and whiskers plots of relative upper limb length vs torso height for Romano-British and Early Medieval females and males.*

The difference between females from these two periods was greater than the difference between females and males in the Romano-British period. When males from both periods were statistically compared to one another, no significant differences were found (*t*-test-MCP: p=0.61) with males from the Early Medieval period exhibiting slightly higher values. A statistically significant difference amongst females from Romano-British and Early Medieval sites was found (Kruskal-Wallis: p<0.01), however a Mann-Whitney pairwise post-hoc test failed to identify where this occurred. Once again, females from the Early Medieval period demonstrate longer upper limbs compared to torso height for their values statistically exceed those of the three sites from the Romano-British period. Unlike the female sample, no statistically significant differences were found between Romano-British and Early Medieval males (one-way ANOVA: p=0.69).

Summary:

- When females and males were compared to one another in each period, only those from the Romano-British period presented statistically significant differences in the relative upper limb length/torso.
- Female and male samples from each period were determined to be similar regardless of which cemetery they were recovered from.
- The relative upper limb length/torso height presented statistically significant differences between periods within the female samples. These differences occurred between females at Roman London, Butt Road, and Poundbury with females in Oxfordshire, Hampshire, and Apple Down. In addition to these sites, a statistically significant difference between females within Eastern sites was present with those from Butt Road and Poundbury. All females from the Romano-British period sites displayed lower values due to longer torsos than females within the Early Medieval period.

6.5.2.9 Relative torso height

The relative torso height assesses the length of the torso in comparison to the length of the lower limbs. It is calculated by summing the body heights of the first thoracic vertebra through the fifth lumbar vertebra, dividing this value by the summed length of femur and tibia, and multiplying by 100. The greater the value of the index, the more equal the torso height will be in comparison to the length of the lower limbs. A total of 19 skeletal elements are needed to calculate the relative torso height and with each skeletal element added, the greater the number of individuals that are eliminated from this sample. Therefore, sample sizes from the Romano-British and Early Medieval sample may be smaller than indices discussed in previous subsections.

A total of 57 females and 72 males from the Romano-British sample had all 19 skeletal elements present to calculate the relative torso height. When compared, statistically significant differences between females and males in relation to their relative torso height were detected (*t*-test-MCP: p<0.01). The mean ratio for females was greater than male mean ratio (49.89 vs 47.20, respectively), indicating longer torsos or shortened lower limbs in females. Greater variation in relative torso height was also seen within the female sample (CV=5.23%) compared to males (CV=4.98%). Higher values in the calculated sexual dimorphism, along with the statistically significant difference between females and males, signal this body proportion as sexually dimorphic (Table 6.62).

Table 6.62: *Summary statistics of the relative torso height for Romano-British and Early Medieval females and males. Shaded cells represent statistically significant differences between females and males.*

	Romano-British Females	**Romano-British Males**	**Early Medieval Females**	**Early Medieval Males**
N	57	72	27	40
Min	42.82	42.08	40.52	38.48
Max	54.62	52.24	50.40	51.87
Mean	49.89	47.20	46.26	45.68
SD	2.61	2.35	2.58	2.64
Coefficient of Variation	5.23	4.98	5.58	5.78
Sexual Dimorphism	-5.54		-0.32	

When females and males were compared amongst the five Romano-British sites, no statistically significant differences within the female (Welch F test: p=0.14) or male (one-way ANOVA: p=0.09) samples were found. Females ranged between 47.45 and 53.17 in mean relative torso height, much greater than the range seen between males from different sites (46.84 and 48.72). Summary statistics for female and male populations within various age categories and sites can be found in Appendix 4 Table 30.

Due to the smaller overall sample size from the Early Medieval period, fewer females and males were present to assess relative torso height than individuals from the Romano-British period. Within this sample, no statistically significant differences were discovered between female and male individuals (*t*-test-MCP: p=0.37). Overall, females demonstrated a greater relative torso height index than males, indicating a slightly longer torso in comparison to lower limb length. However, the coefficient of variation was smaller in the female sample (CV=5.58%) than the male sample (CV=5.78%). The value calculated for sexual dimorphism along with the insignificant difference between the two sexes, indicated that this index is not sexually dimorphic within this sample (Table 6.62). Females and males from the six regions were compared to one another to determine if differences between different geographic locations occurred during the Early Medieval period. Statistically, no significant difference between the sites within similar geographic locations was found within the female sample (one-way ANOVA: $p=0.14$). Greater differences in this proportion were seen between males in various regions. Statistically significant differences were found within the male population (one-way ANOVA: $p<0.01$). Based on Tukey pairwise post-hoc tests, these differences occurred between males in Kent and those from the Hampshire ($p=0.05$), Apple Down ($p<0.01$), and Eastern regions ($p=0.04$). Males from Kent had torso lengths that were longer or lower limb lengths that were shorter, in comparison to the latter three regions. Summary statistics for sites of female and male individuals can be found in Appendix 4 Table 31.

Finally, the relative torso heights of these two time periods were assessed together to explore potential differences in proportion through time (Fig. 6.71). A statistically significant difference between Romano-British and Early Medieval females was found using an independent *t*-test (MCP: $p<0.01$). Females within the Romano-British sample exhibited torsos that were greater in height when compared to the lower limb lengths. A similar pattern within the male sample occurred, with Romano-British males displaying a statistically greater relative torso height than Early Medieval males (*t*-test-MCP: $p<0.01$). Since statistically significant differences between female and male samples were uncovered, statistically significant site-wise differences among females (one-way ANOVA: $p<0.01$) and among males (Kruskal-Wallis: $p<0.001$) from Romano-British and Early Medieval sites/regions were discovered. Tukey pairwise post-hoc tests found statistically significant differences between the Early Medieval region of Castledyke and three Romano-British sites (Roman London: $p=0.01$, Butt Road: $p<0.01$, and Poundbury: $p<0.01$) amongst females. Females from Castledyke had statistically smaller torso heights in comparison to lower limb lengths than Romano-British females. Within the male sample, Mann-Whitney pairwise post-hoc tests found statistically significant differences between those from Roman London and those from both Apple Down (p<0.0001) and Eastern (p=0.0007) regions from the Early Medieval period (Bonferroni-corrected α=0.0017). Like the female sample, males from the Early Medieval period display shorter torso heights in comparison to lower limb lengths than males from the Romano-British period.

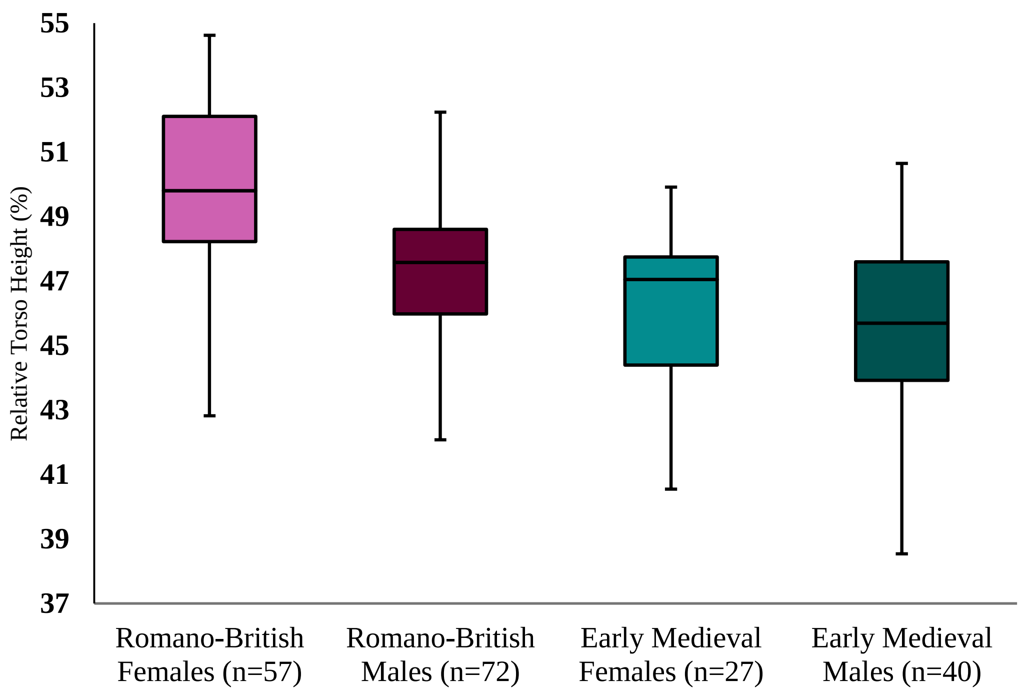


Figure 6.71: *Box and whiskers plots of relative torso height for Romano-British and Early Medieval females and males.*

To summarize results within this subsection:

- Comparisons between females and males with regard to relative torso height found a statistically significant difference within the Romano-British period, but not within the Early Medieval period. Females demonstrated higher values than males, indicating shorter lower limb length compared to torso height.
- Within the Romano-British period, no statistically significant differences occurred within the female and male samples from all five sites. Females from QFM demonstrated the highest values within the sample, whilst males from Butt Road displayed the highest values for

males. Individuals from QFM presented the highest value in sexual dimorphism from all five sites.

- Within the Early Medieval period, differences in relative torso height in males occurred between Kent and three other sites (Hampshire, Eastern, and Apple Down). Females from the Eastern sites and males from Kent sites presented higher values indicating longer lower limb lengths. The greatest amount of sexual dimorphism occurred between the Eastern sites, Apple Down, and Castledyke. The former two sites presented females with higher relative torso height values, whilst the latter demonstrated greater male values.
- When compared through time, relative torso height values decreased significantly between female and male samples. Individuals from the Romano-British period displayed shortened lower limb length in comparison to the Early Medieval sample.
- Statistically significant differences between females from Castledyke and females from Roman London, Butt Road, and Poundbury were present. Females from the Romano-British sample demonstrate shorter lower limb lengths as their skeletal trunk height tends to be greater than females from the Early Medieval sample.
- Statistically significant differences between males from Roman London and males from Apple Down and Eastern regions occurred. Males from the Early Medieval period display elongated lower limb lengths in comparison to torso height, even though they also present longer skeletal torso height than males from the Romano-British sample.

6.5.3 Section summary

The combination of indices and relative lengths of Romano-British and Early Medieval females and males revealed significant differences not just between females and males, but between various body proportions throughout this period. Overall, Romano-British individuals presented shorter lower limbs compared to torso height and stature, whereas Early Medieval individuals presented elongated lower limbs. Through this comprehensive analysis, evidence for the shortening of distal segments, particularly the tibia, has been observed in several indices including the crural and brachiocrural indices and relative lower limb lengths. In order for body proportions to be useful when analysing a population, multiple indices need to be calculated as well as comparisons of long bone lengths.

6.6 Chapter Summary

This chapter has presented a detailed analysis of stress indicators, stature estimations, and body proportion calculations of human skeletal remains recovered from Romano-British and Early Medieval cemetery sites. Greater prevalence of DEH was detected within the Romano-British sample regardless of sex, along with shorter overall stature and differential ratios in various indices. The combination of these analyses reflect a population under stress. An improvement in health was detected with the Early Medieval sample, with a decrease in the prevalence of DEH, increase in stature for males, and indices reflecting greater growth in the lower limbs. Due to these fluctuating body proportions, it was determined that to calculate the most accurate stature, the Fully anatomical method should be employed. It accounts for variation seen within these heterogeneous populations with regard to lower limb lengths and torso lengths. If not all skeletal elements necessary to calculate stature using this method are preset, this chapter has provided population specific formulae to estimate torso length from present vertebral body heights as well as population specific regression formulae to estimate stature from multiple long bone lengths for individuals dating to either period.

Chapter Seven: Discussion

7.1 Introduction

This chapter will discuss the results presented in Chapter Six and integrate the discoveries made with regard to stature estimation methods, body proportions, and stress indicators from the Romano-British and Early Medieval samples analysed in this thesis. A detailed discussion of the errors and inaccuracies of current stature formulae will follow as well as the shortcomings of the Fully method (section 7.2). The benefits of studying overall body proportions rather than single long bone lengths will also be provided. The body proportion data will also be placed within a global ecogeographical context (section 7.3). Finally, stature and body proportion data will be examined in relation to the archaeological context, with a particular focus on childhood stress, living environment, and population mobility (section 7.4).

7.2 Assessment of Stature Calculation Methods

The main aim of this thesis was to derive accurate living statures for individuals from archaeological sites dating to the Romano-British and Early Medieval periods in England. The anatomical method has been established as one of the best methods available to reconstruct living stature from human skeletal remains (Olivier, 1969; Lundy, 1985; Raxter *et al*., 2006; Pomeroy and Stock, 2012); however due to the number of skeletal elements required to successfully utilize this method, researchers often turn to mathematical regression equations. The anatomical method not only provides more accurate stature estimates from human skeletal remains, but also allows for the creation of population specific regression formulae using the archaeological sample as a reference population. These formulae reflect the body proportions seen within the specific target samples and can account for some of the variation seen in these proportions.

Living stature was reconstructed from the Romano-British and Early Medieval samples using the revised Fully anatomical method (Raxter *et al.*, 2006, 2007) and compared to stature calculated using 13 frequently cited mathematical regression formulae (using maximum femoral length, tibial length, and summed maximum femur and tibia length). Most of these regression formulae were unable to accurately estimate stature for females and males within the standard error for each equation. To keep this discussion succinct, only ‘white’ and ‘black’ formulae from Trotter and Gleser (1952, 1958) and Trotter (1970) will be discussed further.

7.2.1 Romano-British female stature estimation

Stature for a total of 40 Romano-British females were estimated using the revised Fully anatomical method as outlined by Raxter *et al.,* (2006, 2007). The majority of standard regression equations overestimated stature. Differences in lower limb lengths and torso height between the Romano-British females and reference samples from which these published regression equations were derived resulted in substantial errors.

7.2.1.1 Trotter and Gleser 1952 and Trotter 1970 regression equations

The majority of osteological reports from Romano-British sites calculate female stature using the regression equations provided in Trotter and Gleser (1952) and Trotter (1970). Jantz and colleagues (1994, 1995) identified that the tibial measurement used to create these formulae was not the maximum length (inclusion of the medial malleolus and exclusion of the intercondylar eminence), but instead excluded the medial malleolus. This is problematic when examining published statures derived from tibial measurements. However, the tibia was a crucial measurement for this study as it is known to be sensitive to adverse circumstances, therefore, it is included here. The measurement of the tibia is also crucial when discussing the implications of possible variations seen in the crural index. All measurements were undertaken by the author.

Results of Giannechini and Moggi-Cecchi’s (2008) study of individuals from Central Italy found that Trotter and Gleser’s ‘white’ formulae tended to overestimate stature, whilst ‘black’ formulae was more accurate. In order to assess whether similar results occurred for the sample analysed for this thesis, both sets of equations (‘white’ and ‘black’) using the maximum length of the femur were compared to stature estimated using the Fully anatomical method as a proxy for ‘known’ stature (Fig. 7.1).

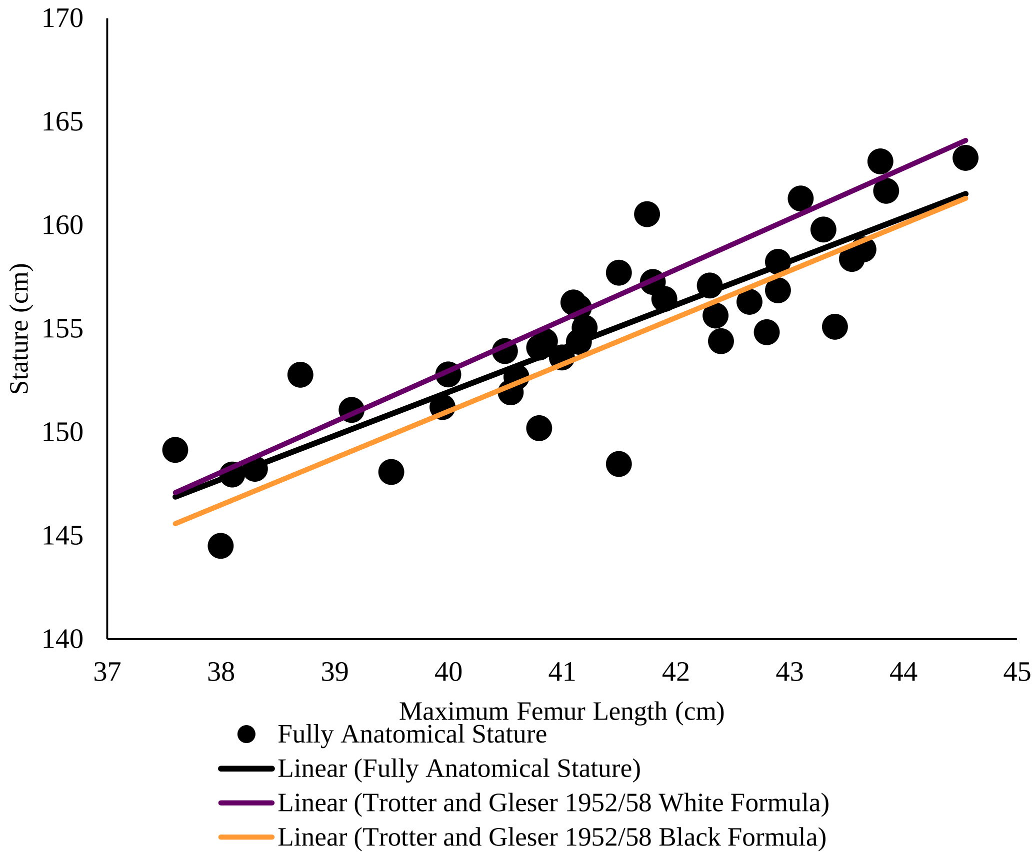


Figure 7.1: *Stature (cm) for Romano-British females plotted against maximum femoral length (cm). Based on femoral length, Trotter and Gleser's (1952/1958) 'white' formula generally overestimates stature, whilst Trotter and Gleser's (1952/1958) 'black' formula generally underestimates stature when compared to the regression line calculated using the Fully anatomical stature.*

From the 40 individuals with 'known' stature, five females had living stature outside the standard error range (±3.72 cm) when calculated using the 'white' formula (Fig. 7.2). The 'white' maximum femoral length regression equation tended to overestimate stature as evidenced by the positive mean PPE (see Appendix 3 Table 11). When 'known' stature was compared to stature calculated using the 'black' formula, a total of seven females had stature estimations outside of the standard error (±3.41 cm) (Fig. 7.2). Unlike the 'white' formula, five of the seven individuals had their stature underestimated by an average of 4.2 cm, whereas only two individuals had their stature overestimated (average 4.8 cm). Both formulae are more accurate than expected as the standard error presumes at least 32%, or 13 of the 40 females, to have stature estimated outside the standard error. The general trend for this formula was to underestimate stature of Romano-British females, as supported by a negative mean PPE (see Appendix 3 Table 12). The error was greater when using the 'white' formula than the 'black' formula. This indicates that the reference population used for Trotter and Gleser's (1952) and Trotter's (1970) 'white' formula (Terry skeletal collection) does not reflect similar body proportions (with regard to femoral length) to many Romano-British females.

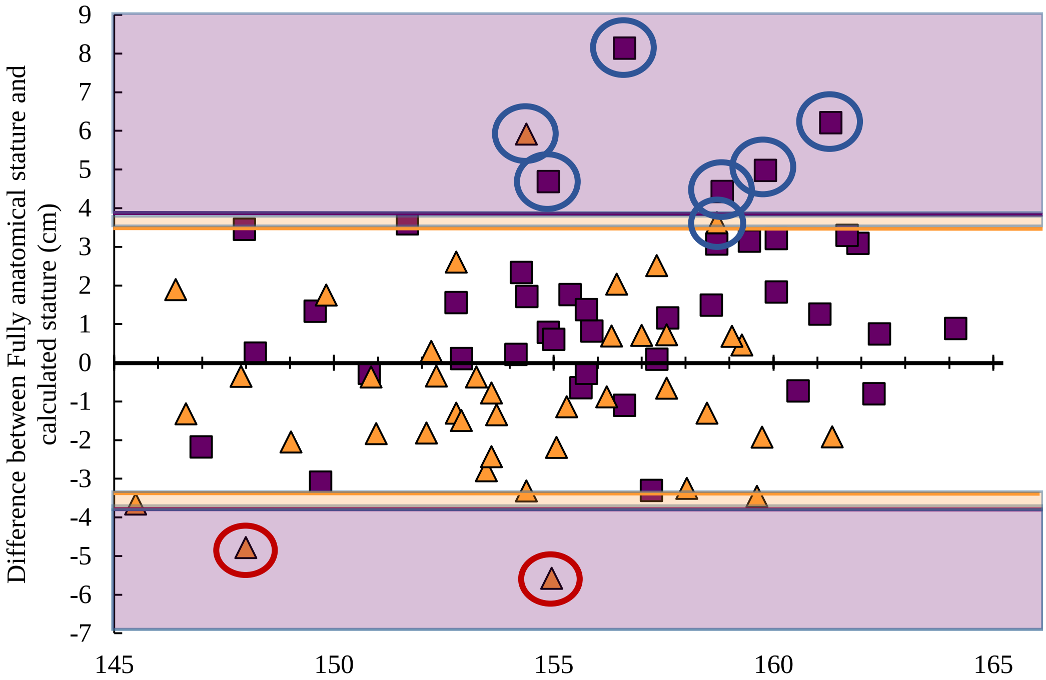


Figure 7.2: *Calculated stature using Trotter and Gleser's (1952/1958) 'white' formula (purple squares) and 'black' formula (yellow triangles) using the maximum femoral length of Romano-British females. Purple lines represent standard error of the 'white' formula (±3.72 cm), whilst the yellow lines indicate standard error for the 'black' formula (±3.41 cm). Individuals who fall outside the standard error associated with the equation are located within the highlighted area. Blue circles represent those who were overestimated and those in the red circles represent those who were underestimated*

When stature is estimated using the length of the tibia, 14 females had their stature overestimated using Trotter and Gleser' (1952)/Trotter (1970) 'white' formula, whilst six individuals had their stature underestimated (and one overestimated) using the 'black' formula (Fig. 7.3). Unlike the 'white' maximum femur formula, the 'white' tibia formula presents a greater number of females outside the standard error range than expected. The number of females with stature inaccurately estimated using the 'black' formula was less than expected statistically, but was also greater than the number of females underestimated using maximum femoral length.

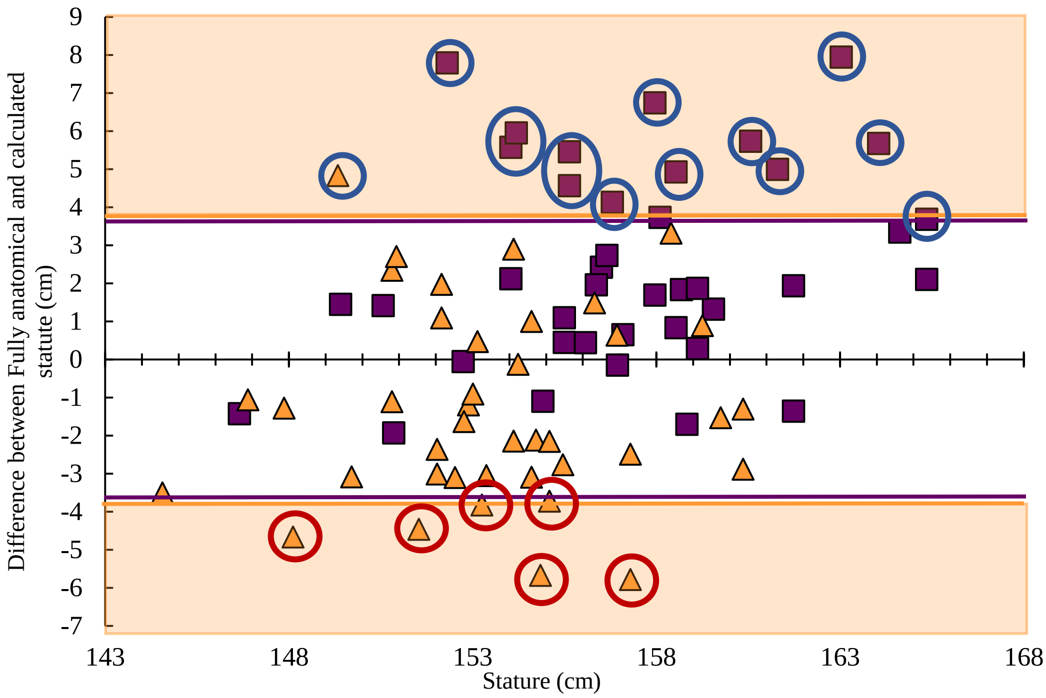


Figure 7.3: *Stature calculation using Trotter and Gleser's (1952/1958) 'white' formula (purple squares) and 'black' formula (yellow triangles) using tibial length. Purple lines represent standard error for the 'white' formula (±3.66 cm) and yellow lines for 'black' formula (±3.70 cm). Individuals falling within the shaded areas fell outside the standard error for each formula. Blue circles highlight those whose stature was overestimated, whilst red circles highlight those whose stature was underestimated.*

Finally, stature calculated from the summed maximum femoral and tibial length using the 'white' equation, overestimated stature by a margin greater than the standard error (average of 5.32 cm) for a total of seven females (Fig. 7.4). When the 'black' formula was used, eight individuals had their stature either overestimated (two females) or underestimated (six females) (Fig. 7.4). The overestimation of stature by the 'white' formula and the general underestimation of stature by the 'black' formula indicate that the reference populations had different body proportions (Fig. 7.4); most likely an elongated torso for the 'white' reference population and a shortened torso for the 'black' reference population. In total, 15 females had stature estimated outside the standard error range by at least one of the three 'white' formulae and only 11 females were within the 'black' formulae error range. Once again, the number of females who had stature estimated outside the standard error was greater than expected for the 'white' formulae (15 of 40), however it was less than expected for the 'black' formulae (11 of 40).

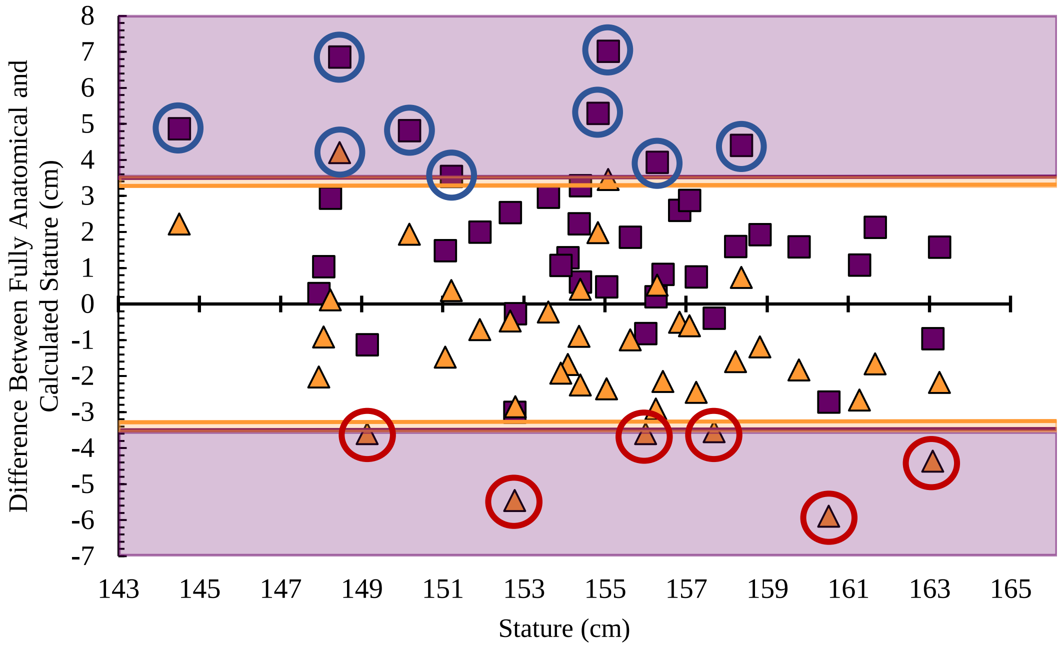


Figure 7.4: *Difference between 'known' (Fully anatomical) stature and calculated stature using the summed lower limb length regression from Trotter and Gleser's (1952/1958) and Trotter's (1970) 'white' (purple squares) and 'black' (yellow triangles) formulae. The 'white' formula generally overestimates stature, whilst the 'black' formula tends to underestimate stature. Purple lines represent the standard error for the 'white' formula (±3.55 cm) and the yellow lines represent the standard error for the 'black' formula (±3.28 cm). Shaded area represents those individuals whose stature were inaccurately estimated. Blue circles highlight those overestimated and red circles highlight those underestimated.*

When the variation of all stature calculations was considered, some information can be gleaned about the important role body proportions play when estimating stature. The Romano-British females from this sample likely have shorter tibiae and/or shorter torso length than the 'white' females from the Terry Skeletal collection, whilst displaying an "elongated" torso compared to the 'black' reference population. The crural index (tibial length/femoral length X 100) for the Romano-British female sample is much lower (80.62) than that reported for the Terry Skeletal Collection ('white'=82.00; 'black'= 83.80) (Raxter *et al.*, 2008). The lower crural index points to shortened tibial length in the Romano-British sample in comparison to both reference samples. This result is unsurprising as the stress experienced during growth and development of females from past populations was likely greater than modern populations. It has been noted by both Frisancho (1993) and Katzmarzyk and Leonard (1998) that variation in stature and body proportions is not only determined by ancestral genes, but also by differential growth based on the surrounding environment. A large proportion (72.0%) of the Romano-

British females who had their stature calculated using the Fully anatomical method demonstrated dental enamel hypoplasia and this, together with the shorter tibiae, indicates a female population under stress during growth and development.

7.2.1.2 Romano-British female population specific regression equations

To assess the accuracy of the new regression formulae created from the 40 Romano-British females using the Fully method as a ‘known’ age, three equations (maximum femur, tibia, and summed femur and tibia) were similarly examined. When maximum femoral lengths were placed in the equation, a total of 13 females had stature calculated outside the standard error (±2.30 cm) associated with the maximum femoral length equation (Fig. 7.5). This demonstrates a normal distribution of those unable to have stature estimated within the standard error using this method with 32% of the sample outside of this range. Seven females were overestimated by an average of 3.65 cm, whilst six were underestimated by an average of 3.24 cm. The roughly equal distribution of those over- or underestimated is expected in an unbiased equation. Fewer females had inaccurate stature estimates using the tibia equation (11 individuals). From these 11 females, seven had stature estimates over the standard error (±2.57 cm) by an average of 4.06 cm and only four were underestimated (average 3.38 cm) (Fig. 7.6).

Finally, stature using the combined length of the maximum femur and tibia were compared to ‘known’ stature and ten females’ stature were calculated outside the error range (±2.19 cm) (Fig. 7.7). It is interesting to note that an equal distribution of those whose stature was overestimated and underestimated was found. In total, 16 females had stature incorrectly estimated using at least one of the three equations. Though this number is greater than Trotter and Gleser’s (1952) and Trotter’s (1970) ‘white’ and ‘black’ formulae, it must be remembered that their standard error range was much greater than the standard error for these population specific formulae. If the standard error associated with each of the ‘white’ and ‘black’ equations were used to determine those whose stature were inaccurately estimated from these three equations, only a total of eight females from the ‘white’ formulae and nine females from the ‘black’ formulae would be incorrectly estimated.

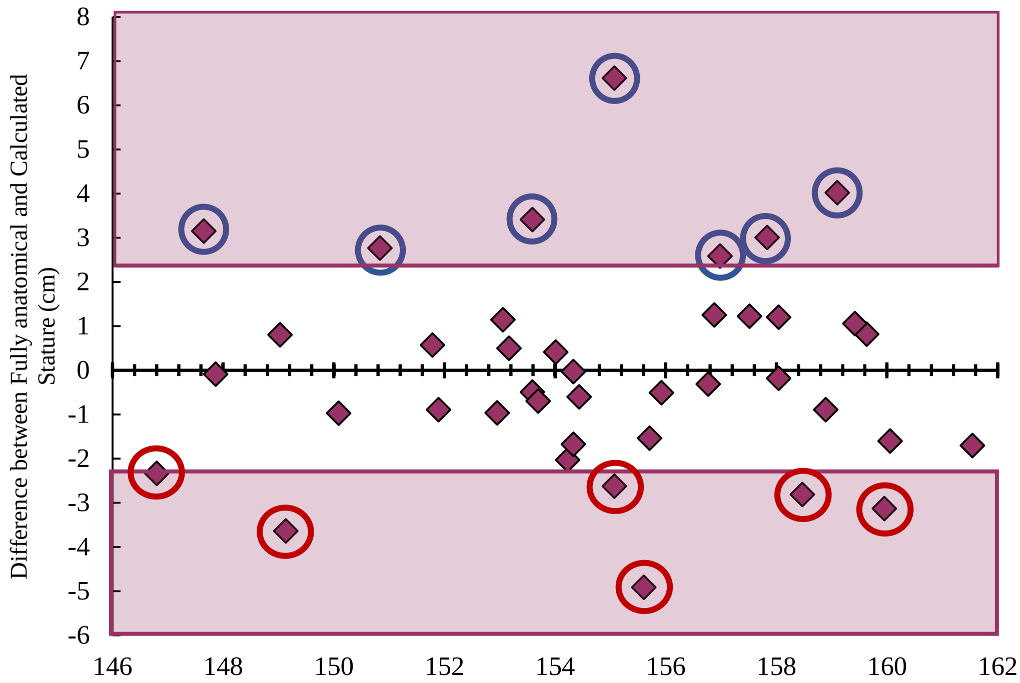


Figure 7.5: *Stature estimated using the Romano-British female population specific maximum femoral length formula (pink diamond). The purple lines represent standard error associated with this equation (±2.30 cm). Shaded area demonstrates those whose stature was estimated outside the standard error. Those females overestimated (blue circles) or underestimated (red circles) are highlighted.*

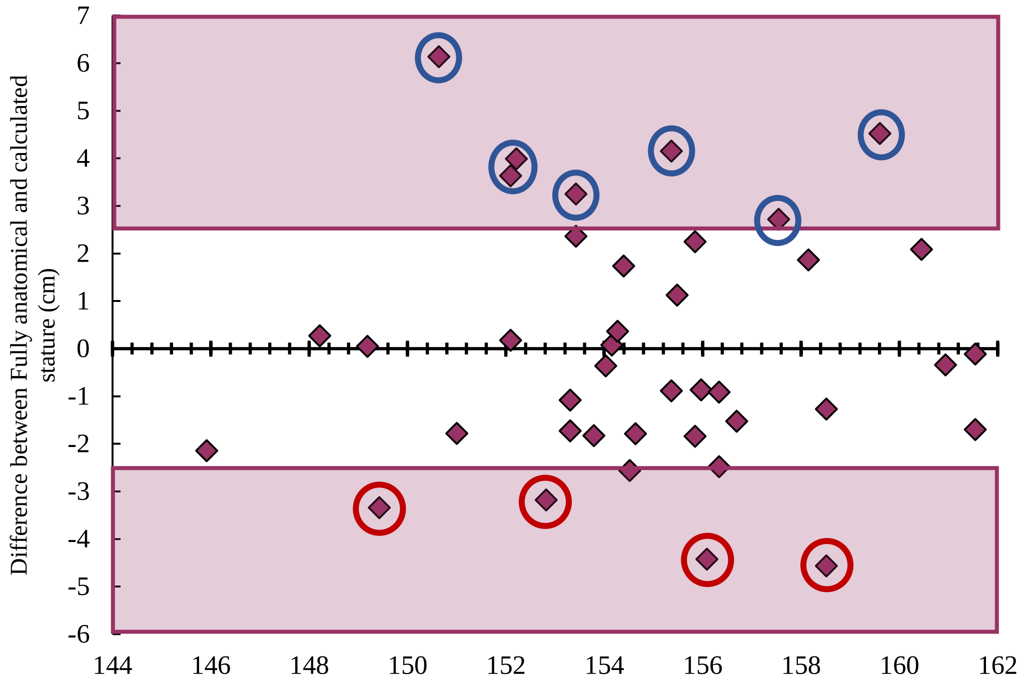


Figure 7.6: *Stature calculations using the Romano-British female population specific tibia length formula compared to 'known' stature. Error bars demonstrate standard error of the equation (±2.57 cm). 'Known' stature highlighted in circles denote females who were overestimated (blue circles) or underestimated (red circles) by a degree greater than the standard error.*

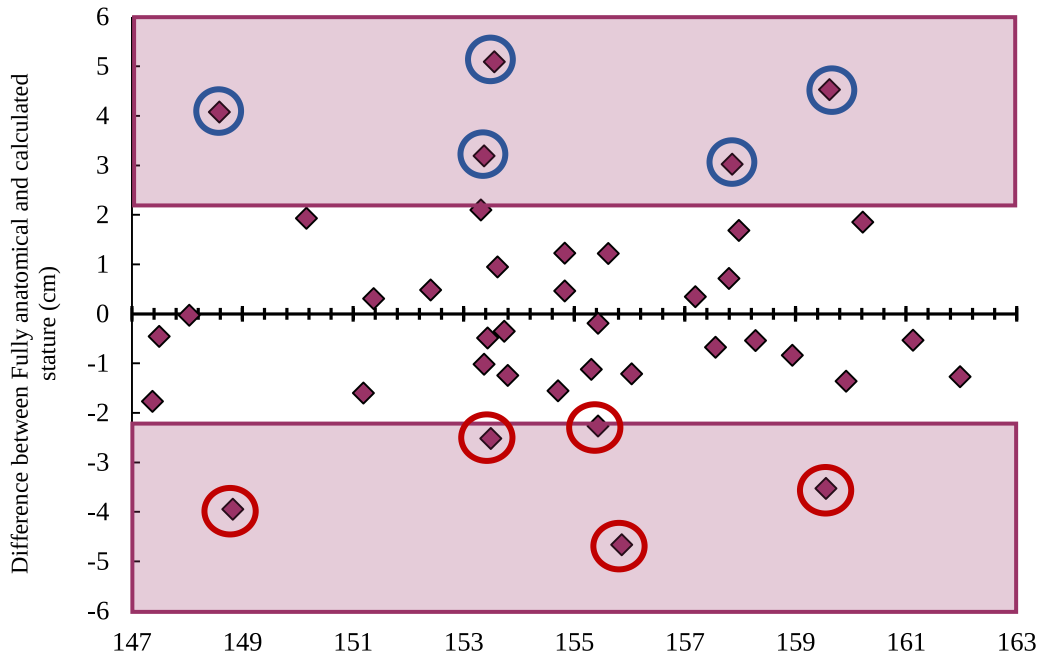


Figure 7.7: *Stature calculated using the population specific summed lower limb length formula. Shaded area represents calculations outside the standard error of the equation (±2.19 cm). Females highlighted in blue circles had their stature overestimated, whilst those highlighted in red circles had their stature underestimated.*

The 16 females whose stature was estimated outside the standard error using the population specific equations will be discussed in greater detail to highlight the role of variation within body proportions and their effect on stature estimation using the mathematical method. Eight of these females were inaccurately estimated by all three population specific formulae and display body proportions that are slightly outside mean proportions of the total female sample. Four of the 16 females had stature incorrectly estimated only when the maximum femur length equation was utilized (Fig. 7.8). All of these females came from the site of Poundbury (skeletons 255, 543, 481, and 1332). Skeletons 255 and 543 had their stature underestimated using this equation (Table 7.1), yet were within the standard error ranges for the remaining two equations. Both females displayed slightly higher crural indices (83.55 and 81.87, respectfully) compared to the mean (80.62) along with elongated torso lengths (47.76 cm and 47.56 cm, respectfully), compared to the mean torso length (46.39 cm). The maximum femur length equation assumes a body proportion where the length of the femur is greater in comparison to the length of the tibia (lower index), therefore when the length of the femur is entered into the equation, it assumes the length of the tibia to be shorter. The assumed shorter length of the tibia coupled with an assumed shorter torso length produces a stature that underestimates the 'known' stature. Of interest, both of these individuals had dental enamel hypoplasia, indicating stress during growth and development.

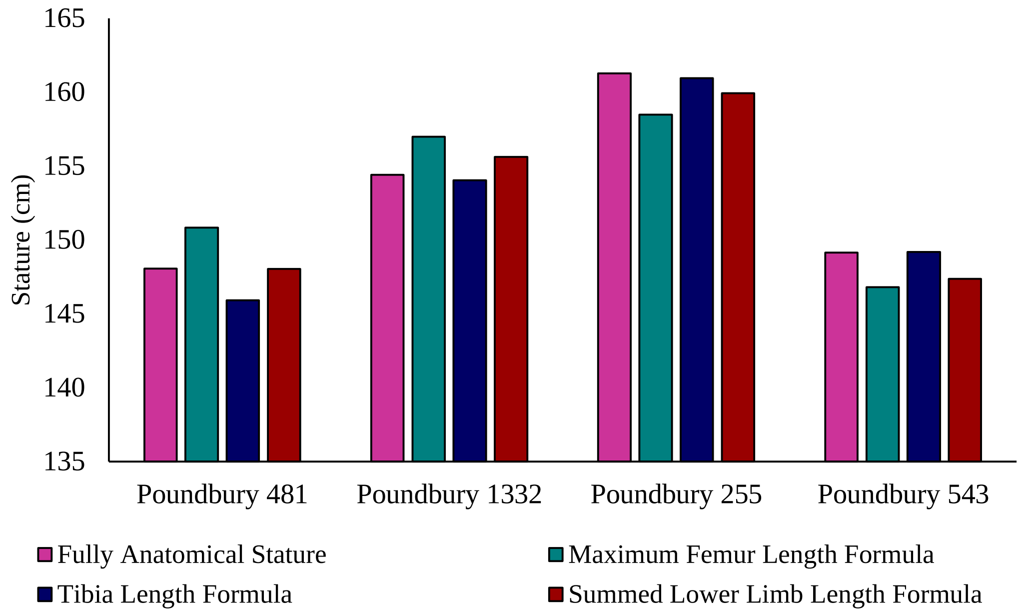


Figure 7.8: *Romano-British females with stature incorrectly estimated from the maximum femur length equation ONLY. Two females (Poundbury 481 and 1332) had stature overestimated whilst the remaining two females (Poundbury 255 and 543) had stature underestimated by a greater margin than the standard error.*

Table 7.1: *Comparison of Fully anatomical stature of Romano-British females to stature calculated using three different population specific formulae. Bold numbers represent stature incorrectly estimated using the maximum femur length with cells shaded blue indicating overestimation and those shaded in peach indicating underestimation of stature greater than the standard error.*

Individual	Fully Anatomical Method	Maximum Femoral Length Formula (±2.30 cm)		Tibia Length Formula (±2.57 cm)		Summed Lower Limb Length Formula (±2.19 cm)	
		Stature	Diff.	Stature	Diff.	Stature	Diff.
Poundbury 481	148.06	**150.83**	+2.77	145.92	-2.15	148.04	-0.03
Poundbury 1332	154.39	**156.98**	+2.59	154.03	-0.36	155.61	1.22
Poundbury 255	161.28	**158.47**	-2.81	160.94	-0.34	159.92	-1.36
Poundbury 543	149.14	**146.80**	-2.34	149.19	+0.05	147.37	-1.77

For two females within this sample stature was overestimated by an amount greater than the standard error (Table 7.1). Both females presented crural indices that were lower (75.26 and 77.86, respectively) than the mean (80.62), along with shortened torso lengths (45.84 cm and 45.39 cm, respectively) compared to mean length (46.39 cm). The equation assumes that an individual will present longer tibial and torso lengths than these two females demonstrate, therefore their stature was overestimated. It is interesting to note that skeleton 481 presents cribra orbitalia, but no dental enamel hypoplasia, whilst skeleton 1332 demonstrates no evidence of stress. These four individuals demonstrate the impact different body proportions can have when using a mathematical method.

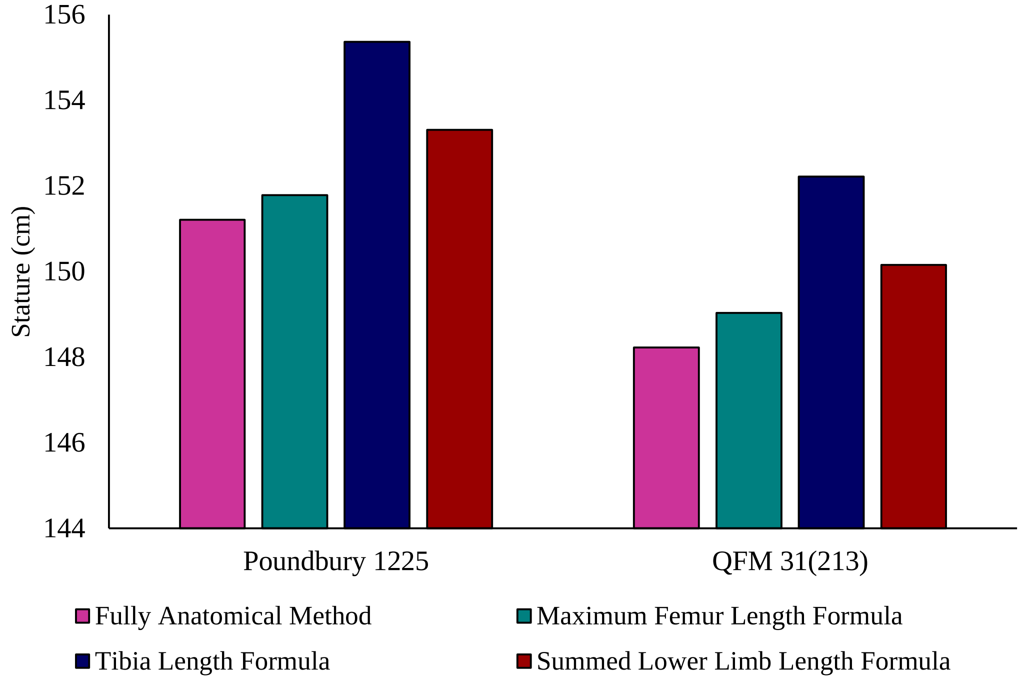


Figure 7.9: *Fully anatomical stature compared to stature calculated using population specific formulae for Romano-British females. These two females (Poundbury 1225 and QFM 31(213)) had stature overestimated using the tibia length ONLY. All other equations estimated stature within their respective standard errors.*

From the 16 individuals mentioned, two females had stature incorrectly estimated using only the tibia length equation (Fig. 7.9). One female was from Poundbury (skeleton 1225) and the other from Queensford Farm/Mill (skeleton 31(213)). In both instances, the tibia equation overestimates stature by an amount greater than the standard error (Table 7.2). Both females demonstrate a crural index higher (84.39 and 83.42, respectively) than the mean crural index (80.62). Along with higher crural indices, both females display shortened torso lengths (43.85 cm and 44.53 cm) in comparison to mean length (46.39 cm). The tibia equation assumes an individual to have longer femora due to a lower mean crural index. Along with the assumption of a longer femur than what is represented in the archaeological population, the equation assumes a greater proportion of stature to come from torso length. Due to the combination of these different proportions, the equation overestimates their stature. Both females display dental enamel hypoplasia, indicating a period of stress experienced during earlier growth and development.

Table 7.2: *Comparison of Fully anatomical stature to stature calculated using three different population specific formulae. Bold numbers represent stature incorrectly estimated using the tibia length with cells shaded blue indicating overestimation greater than the standard error.*

Individual	Fully Anatomical Method (cm)	Maximum Femoral Length Formula (±2.30 cm)		Tibia Length Formula (±2.57 cm)		Summed Lower Limb Length Formula (±2.19 cm)	
		Stature	**Diff.**	**Stature**	**Diff.**	**Stature**	**Diff.**
Poundbury 1225	151.21	151.79	+0.57	**155.36**	+4.15	153.31	+2.10
QFM 31(213)	148.23	149.03	+0.80	**151.51**	+3.99	150.16	+1.93

Two of the 16 females had their stature underestimated using two of the three formulae (Fig. 7.10). The first individual, Poundbury 734, had their stature underestimated using maximum femoral length and the summed lower limb length equations. Their crural index, though slightly higher (81.59), should not have produced such a different stature for both equations. The majority of this underestimation is caused by an elongated torso (49.42 cm). Thus the slightly longer tibia and elongated torso caused this individual to be underestimated using both formulae, whilst underestimating stature using the tibia equation within the standard error. This female presented dentition with pathological signs of stress. The second individual, Poundbury 1004, had stature underestimated using the tibia and summed lower limb length. It is interesting to note that this female displayed a slightly lower crural index (79.12) and a slightly elongated torso (47.44 cm). Due to the slightly lower crural index, the relative length of the femur was considered shorter within both equations, affecting the estimation of stature in the tibia more so than the summed femur and tibia equation

(Table 7.3). Similar to many of the females discussed thus far, Poundbury 1004 presented only dental enamel hypoplasia as a stress indicator.

Figure 7.10: *Comparison of stature calculated using the Fully anatomical method and those estimated using long bone lengths. Poundbury 734 had stature underestimated using the maximum femur length AND summed lower limb length formulae. Poundbury 1004 had stature underestimated using tibia length AND summed lower limb length formulae.*

Table 7.3: *Comparison of all stature equations to the 'known' Fully anatomical stature. Bold stature estimations represent stature that was incorrectly calculated using one of the formulae. Cells shaded in peach represent underestimation of stature by an amount greater than the standard error.*

Individual	Fully Anatomical Method (cm)	Maximum Femoral Length Formula (±2.30 cm)		Tibia Length Formula (±2.57 cm)		Summed Lower Limb Length Formula (±2.19 cm)	
		Stature	Diff.	Stature	Diff.	Stature	Diff.
Poundbury 734	157.69	**155.07**	-3.41	155.85	-1.85	**155.43**	-2.26
Poundbury 1004	156.00	154.33	-1.67	**152.82**	-3.18	**153.79**	-2.51

Finally, females who had their stature inaccurately estimated using all three population specific formulae will be discussed in greater detail. From these eight individuals, five had stature overestimated using all three formulae, whilst three females had stature underestimated (Fig. 7.11). Females who had stature overestimated include one female from Roman London (HOO88 skeleton 835), one from the Roman Suburbs of Winchester (Victoria Road West skeleton 66), and three females from Poundbury (skeletons 385, 568, and 811C). Those whose stature was underestimated include Poundbury skeletons 276 and 1335 and a female from Roman London Spitalfields (SRP98 skeleton 15903). Each individual will be discussed below.

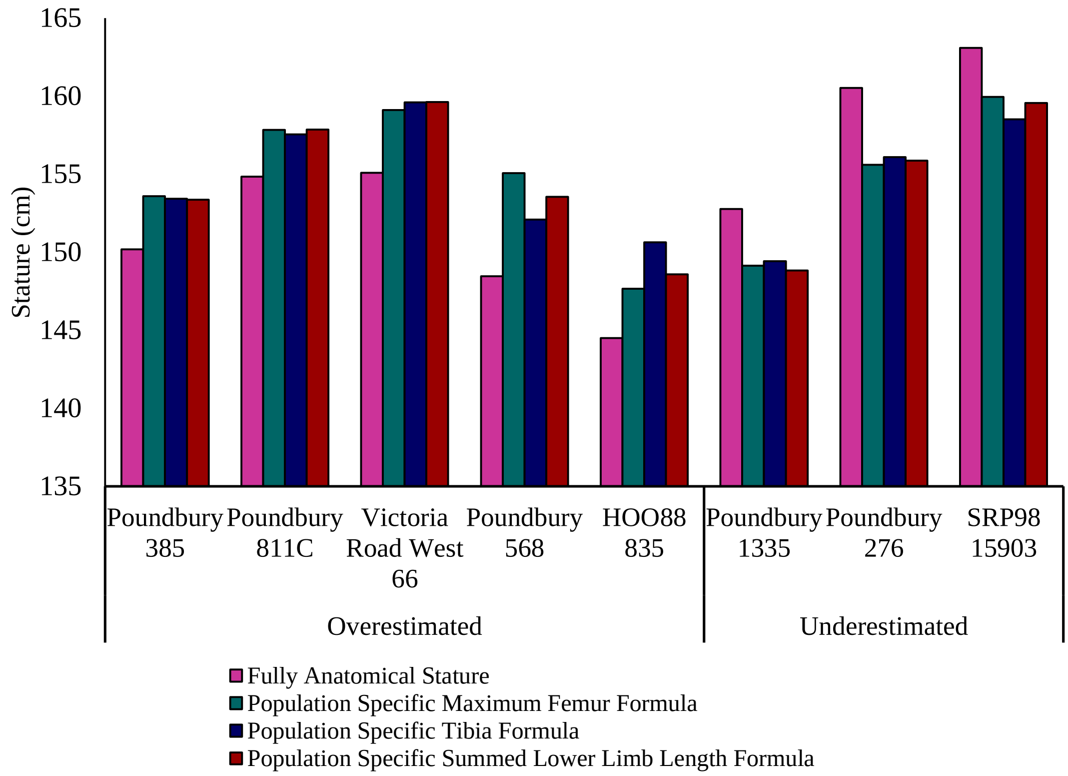


Figure 7.11: *Romano-British females with calculated stature that overestimated or underestimated final stature using all three equations by an amount greater than the standard error associated with each equation.*

All five females who had their stature overestimated by all three population specific regression formulae displayed torso lengths (ΣC2-L5) that were shorter than the mean torso length of the female sample (Fig. 7.12). Three individuals (Victoria Road West 66, Poundbury 385, and 811C) presented crural indices within one standard deviation of the Romano-British female crural index. This indicates that their stature overestimation was caused by the shortened torso length. For example, Poundbury 385 displays long bone lengths similar to the mean lengths within the female sample (Table 7.4) and was expected to have a stature close to the mean Romano-British female (154.83 cm).

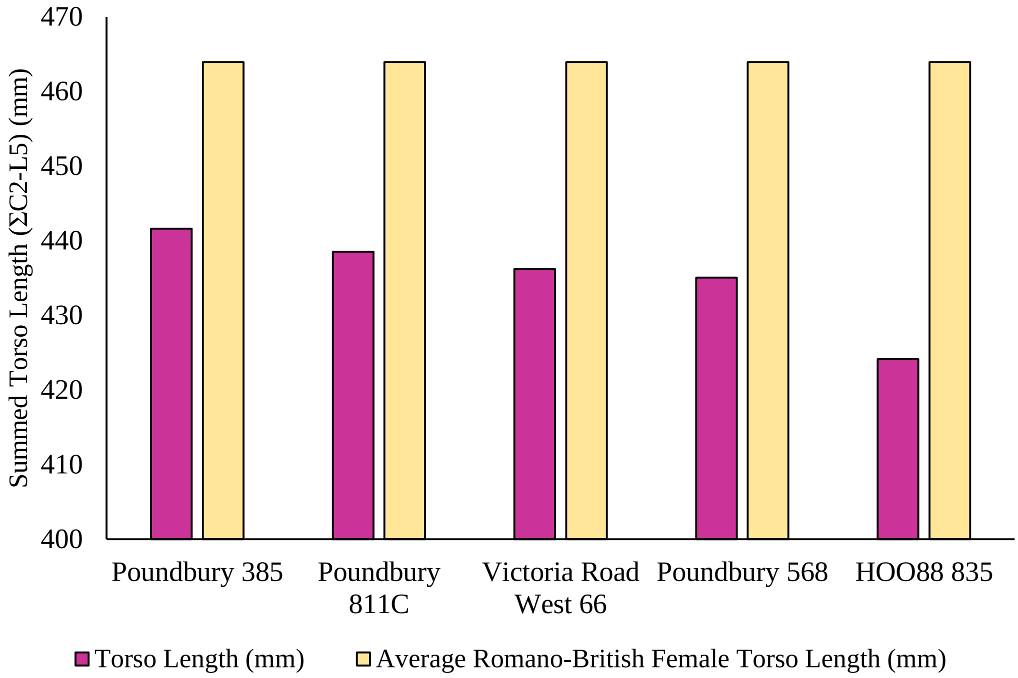


Figure 7.12: *Torso lengths off the five females whose stature was overestimated by all three population specific equations. All torso lengths (pink) are more than one standard deviation (±17.85 mm) away from the mean torso length of Romano-British females (cream colour). Shortened torso lengths are believed to be driving the overestimation of stature for these individuals.*

However, their shorter torso length, which was represented in the Fully anatomical method, shortens their overall stature to 150.18 cm. It must be stated that these females all demonstrate dental enamel hypoplasia, a possible indicator of stress experienced during the development of permanent dentition. Poundbury 811C also displays cribra orbitalia in both orbits. When both torso length and crural index are outside the one standard deviation of the mean, large differences in stature calculated between formulae arise (Fig. 7.13). The shortened torso length and lower crural index for Poundbury 568, along with the presence of both stress indicators, could indicate shortened long bones due to stress experienced during childhood. All five females display dental enamel hypoplasia. The skeletal presentation of stress experienced during growth and development for these females could potentially indicate disruption of growth to the long bones, as the development of permanent dentition occurs simultaneously during the period of long bone growth in childhood.

Table 7.4: *Torso length (ΣC2-L5), maximum femur length, tibia length, crural index, relative torso length, and final stature for all individuals whose stature was overestimated using all three population specific equations.*

Individual	Torso Length (mm)	Maximum Femoral Length (mm)	Tibia Length (mm)	Crural Index	Relative Torso Length	Stature (cm)
Poundbury 385	441.63	408.0	324.5	79.93	47.32	150.18
Poundbury 811C	438.51	428.0	341.5	80.92	45.34	154.83
VRW 66	436.20	434.0	350.0	80.92	42.82	155.08
Poundbury 568	435.07	415.0	319.0	77.71	N/A	148.46
HOO88 835	424.11	380	313.0	82.59	48.63	144.50
Mean of 40 Romano-British Females	463.93	413.83	330.70	80.67	49.75	154.83

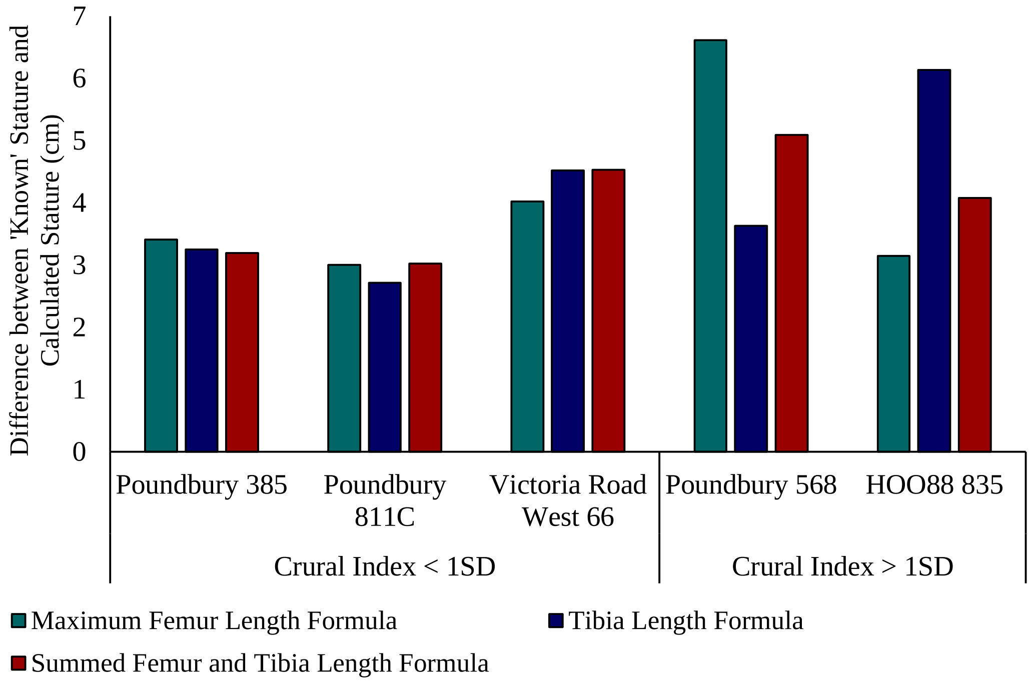


Figure 7.13: *Stature differences between the 'known' Fully anatomical stature and all three stature formulae. Individuals with a crural index within one standard deviation (< 1 SD) of the mean crural index for the sample have three stature calculations (maximum femur, tibia, and summed lower limb) within 5 mm of one another. Those with a crural index outside one standard deviation (> 1 SD) present three stature calculations (maximum femur, tibia, and summed lower limb) with varying degrees of differences between one another.*

Perhaps they experienced stress throughout growth and development, especially during critical periods of long bone growth, impacting the overall length of their tibia and thus producing a lower crural index. The shortened torso lengths for all five individuals impacted the ability of the population specific regression formulae to accurately estimate stature. This shortened torso length could possibly indicate stress experienced throughout the adolescent growth period.

In contrast, three females had stature underestimated utilizing all three formulae due to elongated torsos (Table 7.5) contributing to the underestimation of stature using all three population specific formulae (Fig. 7.14).

Table 7.5: *Torso length (ΣC2-L5), maximum femur length, tibia length, crural index, relative torso length, and final stature for all individuals whose stature was underestimated using all three population specific equations.*

Individual	Torso Length (mm)	Maximum Femoral Length (mm)	Tibia Length (mm)	Crural Index	Relative Torso Length	Stature (cm)
Poundbury 276	509.98	417.5	335.5	81.63	54.32	160.52
Poundbury 1335	483.53	387.0	308.0	79.90	54.62	152.77
SRP98 15903	488.77	438.0	345.5	79.33	49.94	163.08
Mean of 40 Romano-British Females	463.93	413.83	330.70	80.67	49.75	154.83

Based on the long bone lengths from skeleton 276 from Poundbury, this female should be of average stature, however their elongated torso (Fig. 7.14) increased total height significantly. Both Poundbury 276 and SRP98 15903 had dentition present displaying dental enamel hypoplasia, indicating stress experienced during dental development. Perhaps the lower crural index seen in SRP98 15903 (Table 7.5) demonstrates this period of stress, stunting the growth of the tibia during development. Another reason for this low index and elongated torso could be different ancestral genes as this female was identified as a migrant (non-local origin) (Redfern pers comm, 2015).

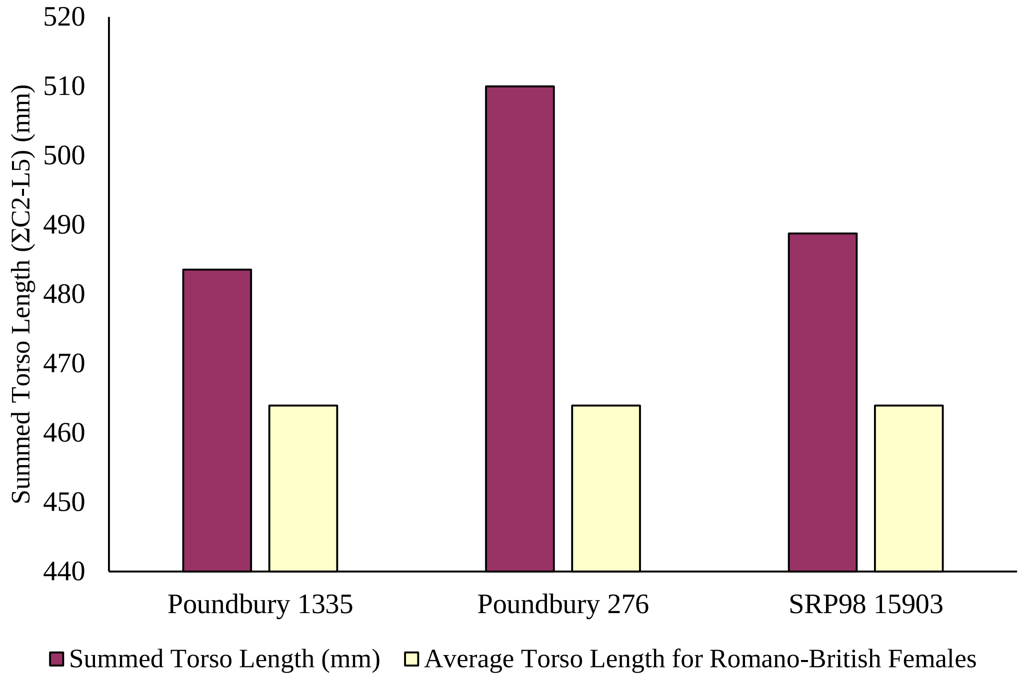


Figure 7.14: *Torso lengths of the three females whose stature was underestimated by all three population specific equations. All torso lengths (pink) are more than one standard deviation (±17.85 mm) away from the mean torso length of Romano-British females (cream colour). Elongated torso lengths are believed to be driving the underestimation of stature for these individuals.*

7.2.2 Romano-British male stature estimation

7.2.2.1 Trotter and Gleser (1952, 1958) and Trotter 1970 calculations

The stature of a total of 29 out of 36 males with 'known' stature was overestimated using Trotter and Gleser's (1952, 1958) 'white' formulae. These 29 males were incorrectly estimated using one, two, or all three formulae using lower limb long bone lengths (maximum femur, tibia, and summed lower limb length). As demonstrated in Figure 7.15, 28 of the 36 males had stature overestimated greater than standard error (±3.94 cm) using the equation for maximum femoral length. A few of these individuals (nine males) had their stature inaccurately estimated using maximum femur length only because they had crural indices outside the standard error of the reference sample. The mean crural index for the Terry Skeletal Collection's 'white' sample is 81.9 ±0.4 (Raxter *et al.*, 2008).

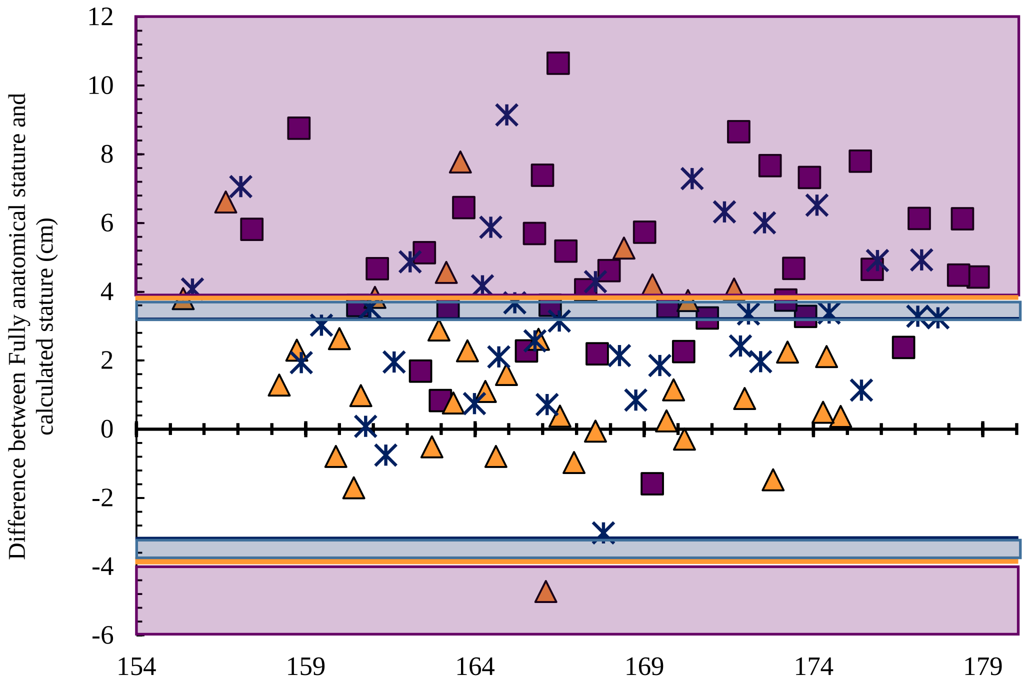


Figure 7.15: *Stature calculated using Trotter and Gleser (1952, 1958) 'white' (purple squares), 'black' (yellow triangles), and Trotter (1970) 'white' (blue star) maximum femur length formulae. Standard error of the equation for Trotter and Gleser (1952, 1958) 'white' (±3.94 cm), 'black' (±3.91 cm), and Trotter (1970) (±3.28 cm), represented by purple, yellow, and blue lines, respectively.*

It indicates that Trotter and Gleser's (1952, 1958) 'white' maximum femur equation assumes a relatively longer tibial length than Romano-British males possessed and therefore generally overestimates stature. Fewer males had stature incorrectly estimated using the equation for tibial length (Fig. 7.16). The majority of Romano-British males fall below the reference sample's mean crural index, therefore Trotter and Gleser's (1952, 1958) equation estimates a stature shorter than the maximum femur. For example, if the length of a tibia is 369 mm, the mean crural index for the Romano-British male sample (80.10) would estimate the maximum femur length to be approximately 460 mm; the maximum femur length shortens to 450 mm when estimated using the mean crural index from the Terry skeletal collection (81.9), one full centimetre shorter. The shortening of the femur reduces the overall estimation of stature, which is why more Romano-British males fall within Trotter and Gleser's (1952, 1958) standard error for the measurement of the tibia. A total of 17 individuals had stature overestimated using the summed lower limb length equation due to reasons mentioned above (Fig. 7.17).

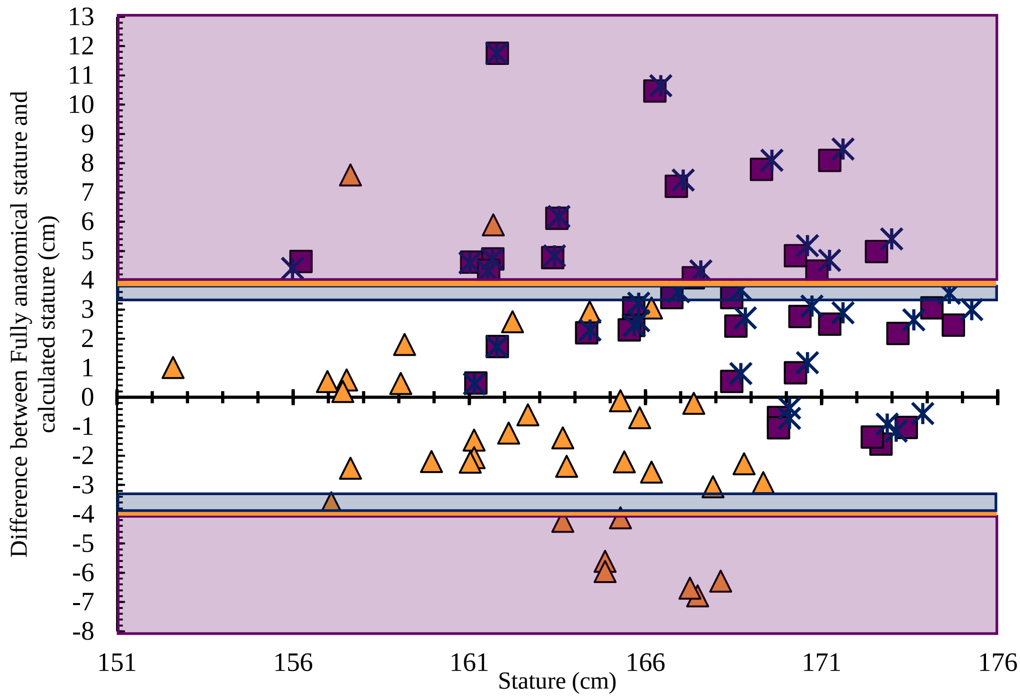


Figure 7.16: *Stature and calculated stature using tibial length formula from Trotter and Gleser (1952, 1958) and Trotter (1970) publications. Purple squares represent the 'white' formula, the yellow triangles represent the 'black' formula, and blue stars represent 'white' formula from Trotter (1970). Standard error represented with purple ('white' formula) (±4.00 cm), yellow ('black' formula) (±3.96 cm), and blue ('white' formula 1970) (±3.37 cm) lines. Individuals within the shaded area had stature inaccurately estimated.*

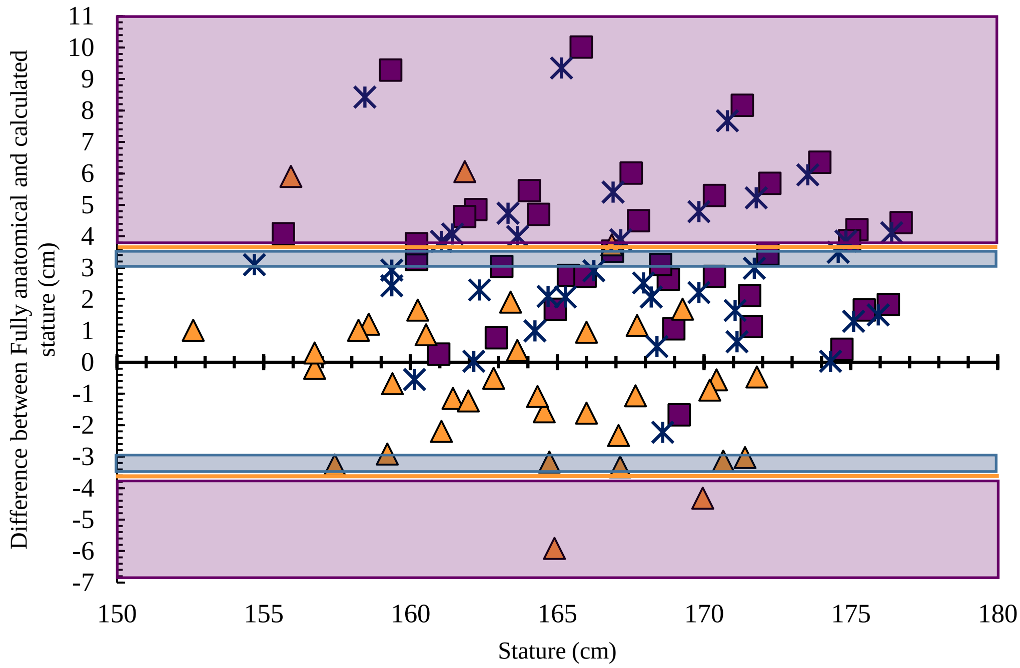


Figure 7.17: *Stature calculated using Trotter and Gleser's (1952, 1958) 'white' (purple squares) and 'black' (yellow triangles), as well as Trotter's (1970) 'white' (blue stars) summed lower limb length formulae. Standard error of the 'white' (±3.74 cm), 'black' (±3.68 cm), and 'white' (1970) (±2.99 cm) in their respective colours.*

The different relative lower limb lengths between the reference population and the Romano-British males is believed to be driving the inaccurate estimations of stature using this formula.

Unlike Trotter and Gleser's (1952, 1958) 'white' formulae, the 'black' formulae were more accurate for Romano-British males. Generally, the formulae from the 'black' reference sample from the Terry skeletal collection demonstrate longer tibia and shorter torso lengths overall. The mean crural index for the reference population is 83.7 ±0.4 (Raxter *et al*., 2008). A total of 12 males had stature inaccurately estimated using one, two, or all three regression equations (maximum femur, tibia, and summed lower limb length). Six males had stature overestimated/underestimated using the maximum length of the femur, of which three were only wrongly estimated by the femur equation only (Fig. 7.15).

All six males display lower crural indices than the Terry skeletal collection mean, meaning their tibial lengths are shorter in relation to femur length than the reference sample. The maximum femur equation therefore assumes longer tibial lengths due to the higher crural index and therefore overestimates stature. Only eight males were incorrectly estimated using the tibial length equation, with five individuals being inaccurately estimated with the tibia equation only (Fig. 7.16). Six of these males were underestimated using this equation.

Due to the higher crural index, the 'black' tibia equation assumes a shorter femur length in relation to tibial length, thereby underestimating stature. Interestingly, two individuals (Poundbury 119 and SRP98 15641) had stature overestimated using this equation. Upon further analysis, these two possess the shortest torso lengths (430.94 mm and 430.91 mm, respectively) in the total male sample (mean torso length=483.79 mm). The five centimetre difference in torso lengths contributed to the overestimation of stature based on the tibia equation. When stature is calculated using the summed lower limb lengths, only four males were inaccurately estimated (Fig. 7.17).

Three of these males (Andover Road 319, Poundbury 119, and SRP98 15641) were overestimated and presented lower crural indices along with shortened torso lengths, whilst one male (Poundbury 1164) was underestimated due to an elongated torso length (526.67 mm). Overall, the higher crural index and most likely shortened torso lengths for the ‘black’ reference population from the Terry skeletal collection caused equations to overestimate when using maximum femur length and summed lower limb length, whilst underestimating stature when using tibial length.

Finally, the regression formulae presented in Trotter’s (1970) publication are slightly different to those from the previously mentioned publications. Using these formulae a total of 23 males were incorrectly estimated, with more males being overestimated (13 individuals) using all three formulae. Eighteen males had stature incorrectly estimated using the maximum femur length (Fig. 7.15), three of which were only overestimated using this equation only. The same number of males were overestimated using the length of the tibia. When the torso length of a Romano-British male is within one standard deviation of the mean and has a higher crural index, it is more likely that this equation will estimate stature within the standard error; however if the torso length is shorter and crural length lower stature is likely to be overestimated. Fewer males had stature overestimated using the summed lower limb length that the previous two equations (Fig. 7.17). Generally, the lower crural indices of Romano-British males produce stature estimates that are taller than the ‘known’ stature, even when torso length is considered within one standard deviation of the sample. The equations presented by Trotter and Gleser (1952, 1958) and Trotter (1970) do not accurately reflect similar body proportions to the Romano-British male sample. Trotter and Gleser (1958) also found differences between regression formulae created using a combination of World War II casualties and the Terry Collection when compared with casualties from the Korean War leading them to amend their equations.

7.2.2.2 Population specific regression formulae created for Romano-British males

From the sample of 36 Romano-British males with ‘known’ stature, a total of 17 were inaccurately estimated using one, two, or all three population specific formulae. Though the number of males with stature estimations outside standard errors for each equation is greater than the number of males incorrectly estimated using Trotter and Gleser’s (1952, 1958) ‘black’ formulae, it must be noted that the population specific standard errors are over one centimetre smaller than those for Trotter and Gleser’s (1952, 1958) ‘black’ equations. The larger standard errors for Trotter and Gleser’s

(1952, 1958) ‘black’ formulae would include many males who were determined to be outside the range using the population specific formulae.

Twelve males had stature estimated outside the standard error of the maximum femur equation (Fig. 7.18). A third of these males had stature incorrectly estimated using only this equation (all from Poundbury), whilst the remaining two-thirds had stature incorrectly estimated using the tibia and/or the summed lower limb length equations. The equation using the maximum femoral length overestimated individuals’ stature by an average of 3.57 cm and underestimated stature by an average of 2.86 cm, which is under the standard errors associated with both the ‘white’ and ‘black’ formulae from Trotter and Gleser (1952, 1958), ±3.94 cm and ±3.91 cm, respectively.

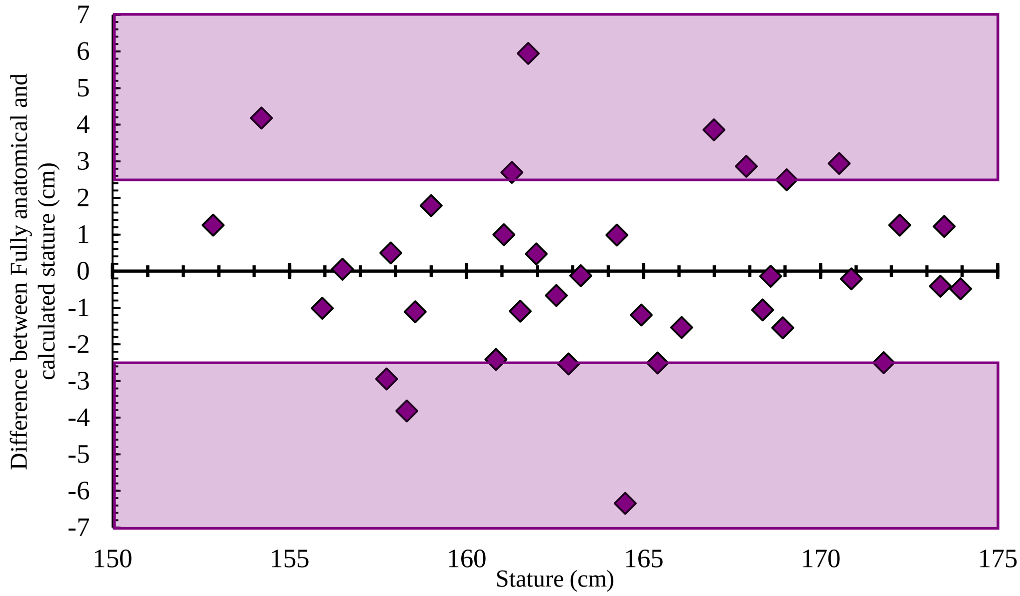


Figure 7.18: *Population specific stature calculation using the maximum femur length plotted against difference from the Fully anatomical stature. Standard error of the equation represented by purple line (±2.47 cm). Shaded area represents individuals whose stature was either overestimated or underestimated.*

Nine males were incorrectly estimated using tibial lengths with five individuals being overestimated and four underestimated (Fig. 7.19) by an average of 4.43 cm and 2.81 cm, respectively. Finally, a total of 10 males had stature inaccurately estimated using the summed lower limb length equation (Fig. 7.20). The majority of these males display crural indices outside one standard deviation of the mean and/or torso lengths that are elongated/shortened. These individuals present body proportions that vary from the mean, thus making estimating stature difficult using these population specific formulae.

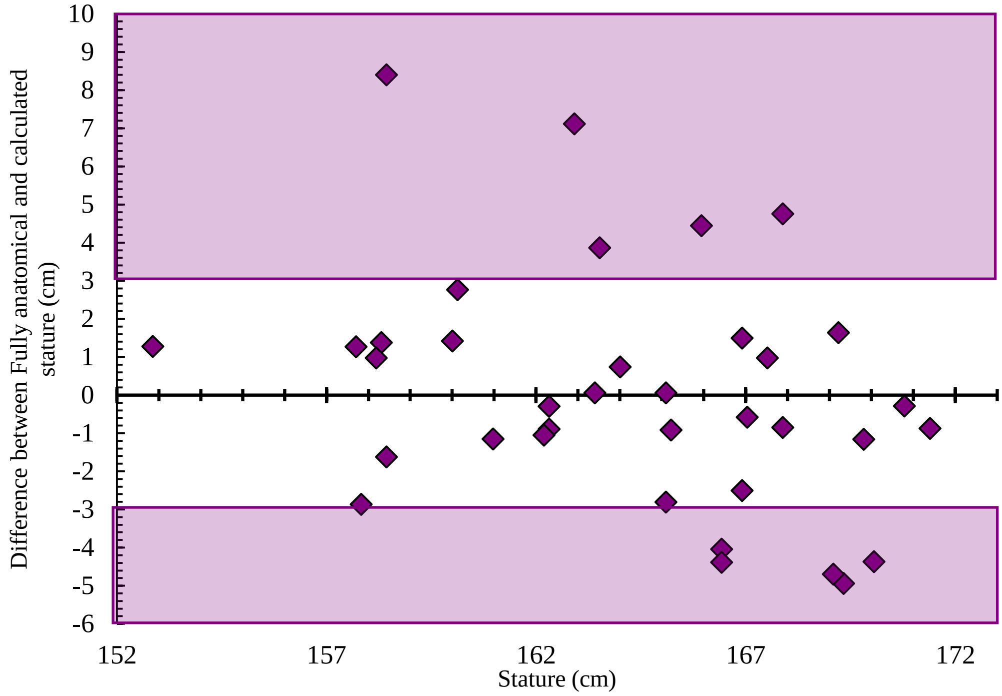


Figure 7.19: *Stature calculated using the population specific tibia length formula plotted against the difference between calculated stature and Fully anatomical stature. Calculated statures outside of standard error (±2.96 cm) located within the purple shaded area.*

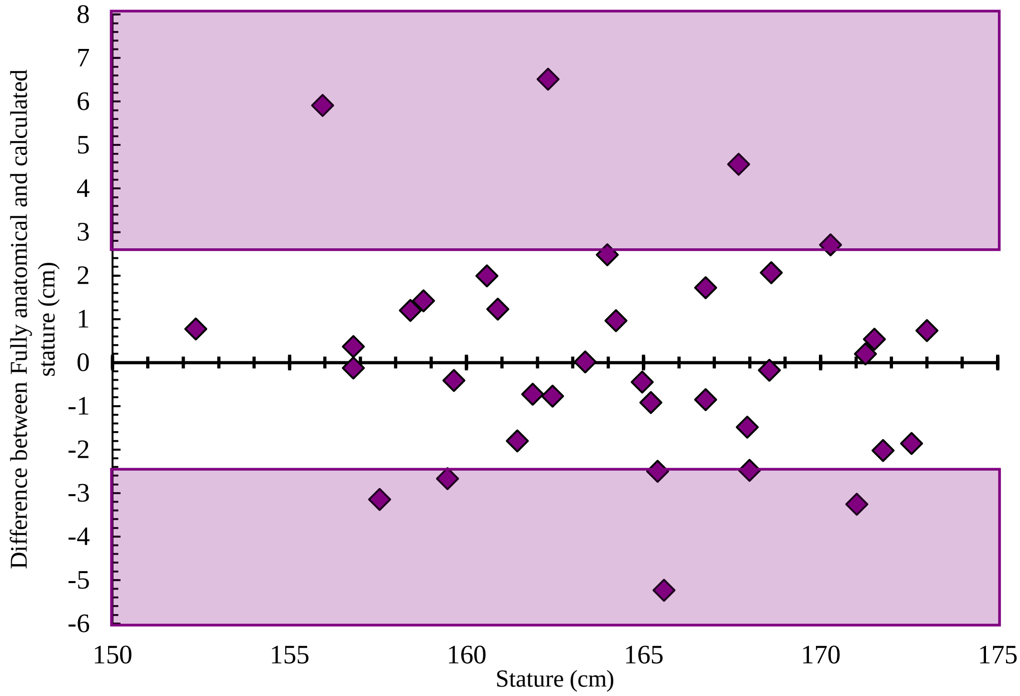


Figure 7.20: *Estimated stature using the population specific lower limb length equation plotted against difference between the Fully anatomical statures. Purple lines represent the standard error associated with the equation (±2.46 cm). Those males with estimated stature outside of the standard error are located within the shaded region.*

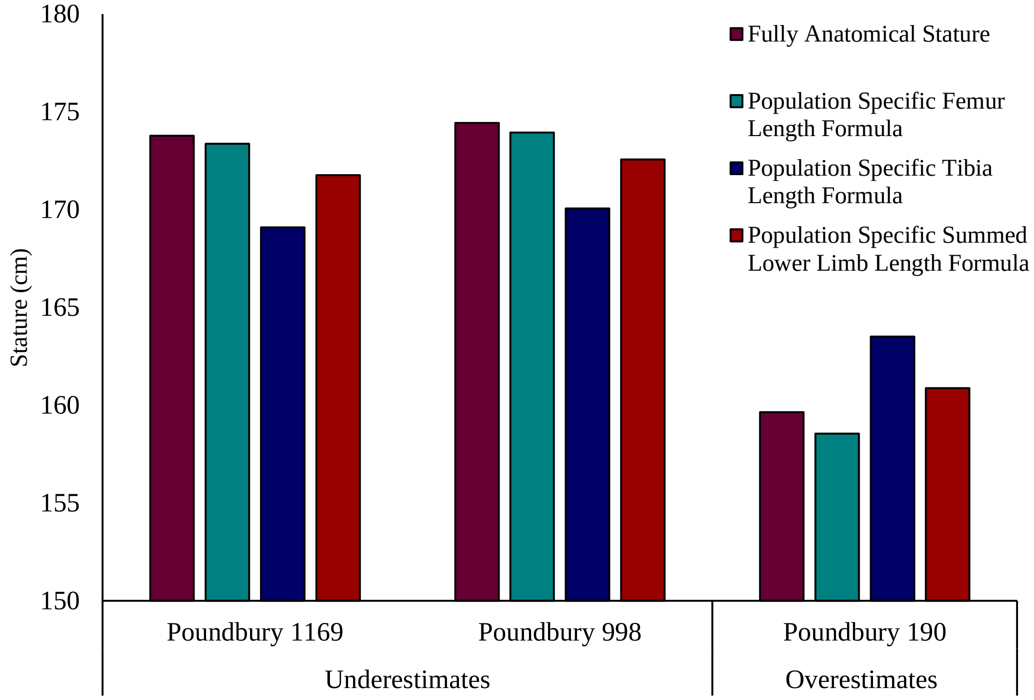


Figure 7.21: *Romano-British males with stature inaccurately estimated using the tibial length equation only. Poundbury 1169 and 998 present lower crural indices, whilst Poundbury 190 presents a higher crural index.*

Three of the four males who had stature incorrectly estimated using the maximum femoral length possessed both higher and lower crural indices. Only skeleton 247 from Poundbury displays a crural index within one standard deviation. All three males with incorrect stature estimation using the tibia length formula only demonstrate crural indices outside the one standard deviation range (Fig. 7.21). Specifically, Poundbury skeletons 998 and 1169 possessed longer torsos and lower crural indices. Usually, shortened tibial lengths indicate stunting during growth and development (Tanner *et al.*, 1982; Bogin, 1999), however since there are no other signs of stress during this period, perhaps their proportions are 'normal' and not stunted. If these proportions represent an individual with no stunting, their lower crural index and longer torso length demonstrate a body that is well adapted to a cooler environment (Auerbach, 2007) and perhaps local. To test this hypothesis, isotopic analysis using strontium, oxygen, carbon, and nitrogen on both enamel and bone would need to be conducted to assess the mobility and diet of these individuals. The third male, Poundbury 190, presents a higher crural index (84.07) with a torso length almost a centimetre shorter than the mean length. Along with a shortened torso length, their femoral length is relatively short in comparison to the tibial length. The mean length of a femur within this sample (for an individual with a tibial length of 362 mm) would be 438.5 mm (compared to actual measurement of 417.5 mm). The shortened torso length and higher crural index could indicate an individual who might not be local to Roman Britain, however the presence of both cribra orbitalia and dental enamel hypoplasia suggest a possible impact on long bone growth during childhood development.

Unlike the female sample, only four males had stature incorrectly estimated using all three formulae. Three of these males display torso lengths that are shorter than the mean for the sample (Fig. 7.22). Shortened torso length compared to mean lengths could be explained by possible growth disruptions during adolescence, when growth in the trunk peaks (Tanner, 1990; Karlberg, 1998; Wilson, 2001), or could be indicative of an individual who may possess different ancestral genes which impact body proportions.

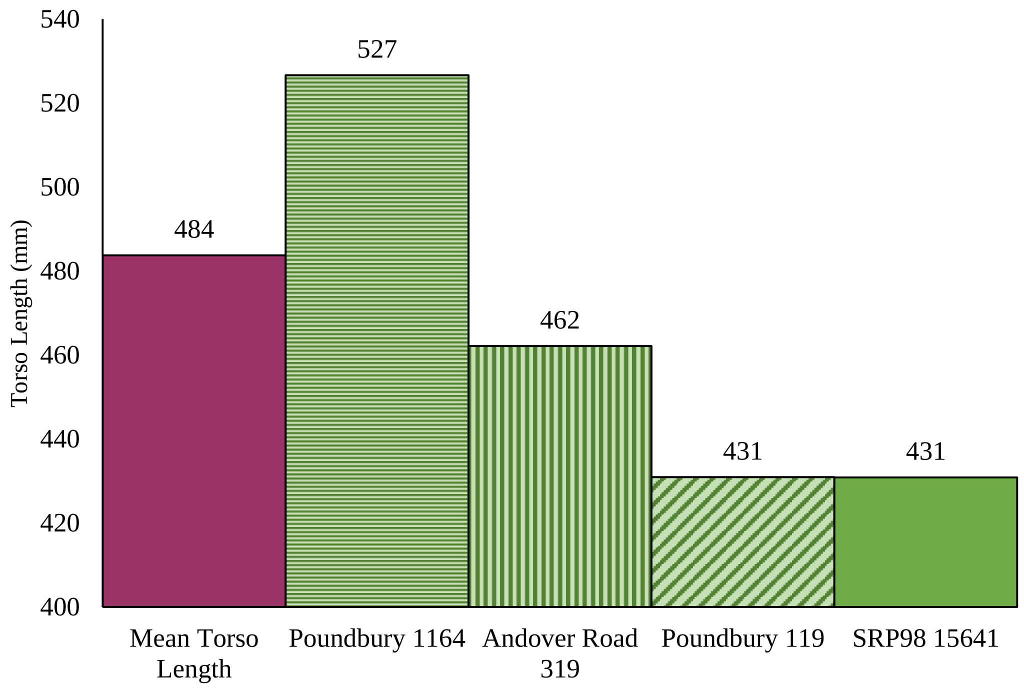


Figure 7.22: *Torso length of Romano-British males whose stature was incorrectly estimated using all three population specific regression formulae versus the mean torso length of the total male sample.*

The only male from Roman London had stature overestimated by all three formulae and was extremely short (150.03 cm vs mean 164 cm). Their lower limb lengths were much shorter than the mean and their torso length is almost five centimetres shorter than the mean lengths (Fig. 7.22). The higher crural index of this male most greatly affects the calculation of stature using the tibia as this equation assumes both a longer femur and longer torso length. As discovered within the female sample, individuals with crural indices different from the mean tend to produce stature estimations that are vastly different depending on skeletal elements used to predict stature. Although the relationship between torso length and crural index is not as strong in the males as it is in the female sample, the majority of these individuals follow this pattern.

7.2.3 Early Medieval female stature estimation

Very few females dating to the Early Medieval period were reconstructed using the Fully anatomical method due to smaller cemetery sites and taphonomic damage. Though 247 females were analysed in total, only eight females had all of the necessary skeletal elements present for the Fully anatomical method. For early medieval samples, most researchers use Trotter and Gleser's (1952, 1958) or Trotter's (1970) formulae to estimate stature from single or multiple long bone measurements. This section will assess the accuracy of these equations and a critical analysis of the population specific equations for Early Medieval females, including an analysis of body proportions.

7.2.3.1 Trotter and Gleser (1952, 1958) formulae

Seven of the eight females with 'known' stature were incorrectly estimated using one, two, or all three 'white' formulae from Trotter and Gleser's (1952, 1958) and Trotter's (1970) publications (Fig. 7.23). Three females (Apple Down 50, Caister-on-Sea 84 and 136) had stature overestimated using the maximum femur length. All three females present lower crural indices than the Terry Collection's mean for 'white' females (82.0 ±0.4). The 'white' formula using the maximum femur length assumes a longer tibia due to the higher crural index. When utilizing the measurement of the tibia, four females (Apple Down 4B, Abingdon 50(2452), Alton 23, and Caister-on-Sea 144) were overestimated by an amount greater than the standard error association with this formula (Fig. 7.24).

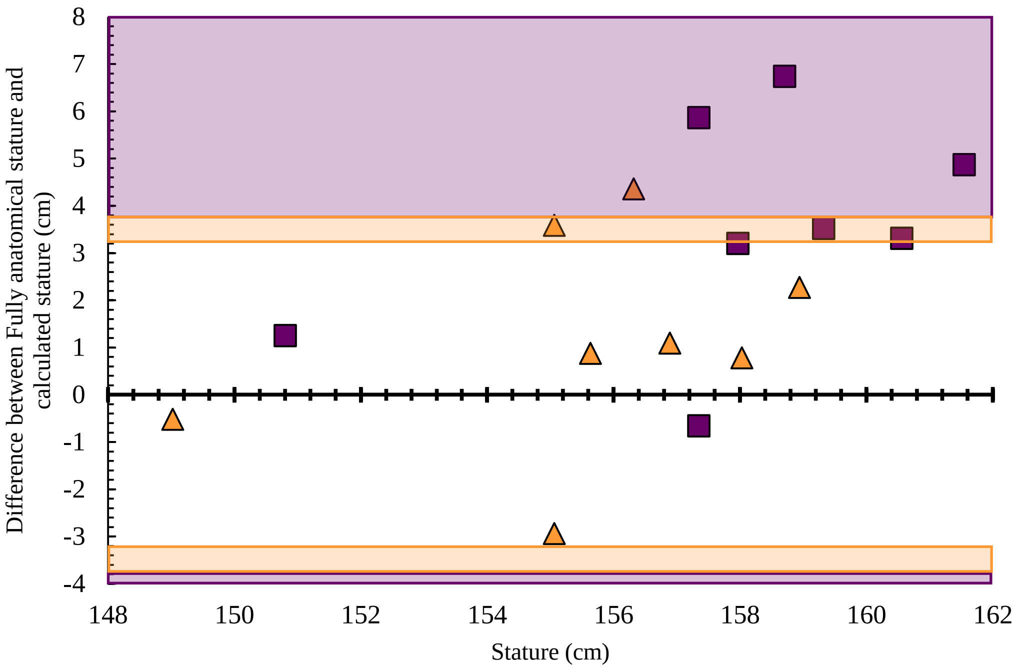


Figure 7.23: *Trotter and Gleser's (1952, 1958) 'white' (purple squares) and 'black' (yellow triangles) compared to 'known' Fully anatomical stature of Early Medieval females. Purple and yellow lines represent standard error associated with the 'white' maximum femur length formulae (±3.72 cm) and the 'black' maximum femur length formula (±3.28). Individuals within the shaded areas had stature inaccurately estimated using these formulae.*

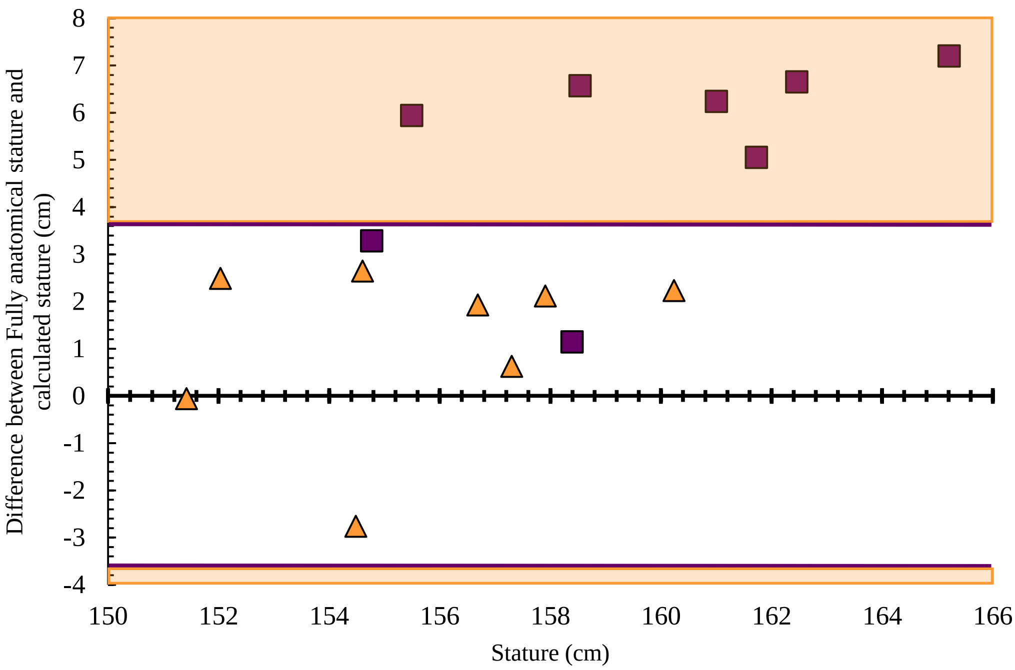


Figure 7.24: *Early Medieval stature estimation using the 'white' tibia length formula (purple square) and 'black tibia length formulae (yellow triangle) from Trotter and Gleser's (1952, 1958) publications. Standard error for the 'white' regression formulae in purple (±3.66 cm) and standard error for 'black' regression formula (±3.70) in yellow. Individuals whose stature was inaccurately estimated within shaded area.*

Two of these individuals (Apple Down 4B and Caister-on-Sea 144) display a higher crural index than the reference population (85.94 and 83.29, respectively). Finally, five females had stature overestimated using the summed lower limb length equation (Fig. 7.25). Three of these females also had stature overestimated using the maximum femur equation, whilst the remaining two were overestimated using the tibia length equation. Those whose summed lower limb length inaccurately predicted stature present different relative lower limb lengths or torso lengths than those of the reference population. Due to these differences between the Terry Collection 'white' reference population and the Early Medieval female sample, these formulae are unable to accurately estimate stature.

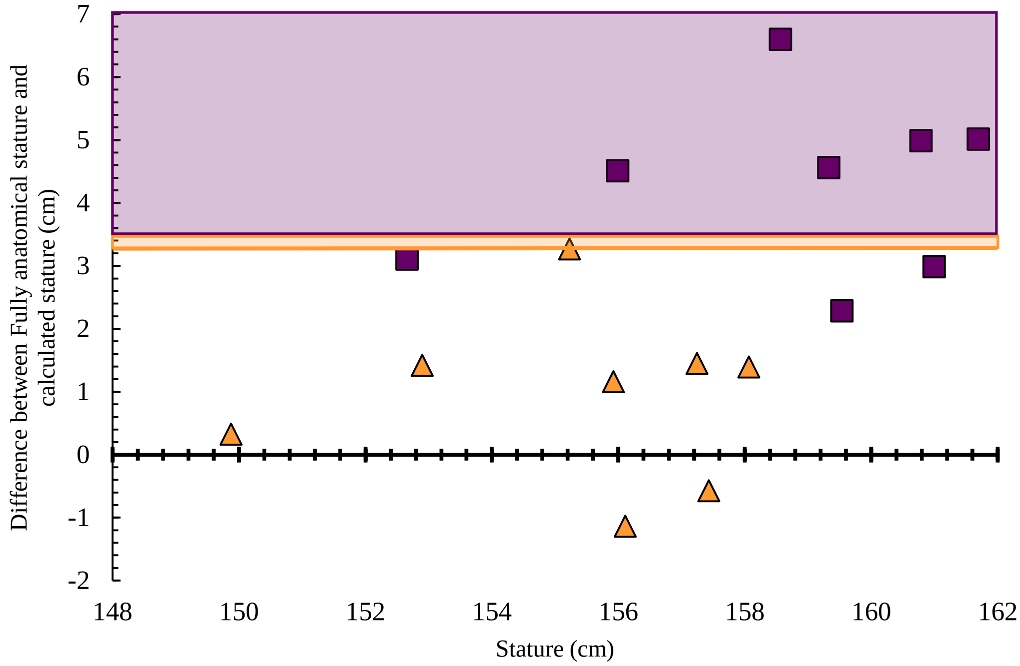


Figure 7.25: *Early Medieval female stature estimation using the 'white' summed lower limb length formula (purple square) and the 'black' summed lower limb length formula (yellow triangle). Standard error for the 'white' formula (±3.55 cm) is represented with a purple line and the standard error for the 'black' formula (±3.28 cm) is presented with yellow lines.*

When the formulae created from the Terry Collection 'black' sample were used to estimate stature, two females were inaccurately estimated. These two females (Caister-on-Sea 84 and 136) had their stature overestimated when the maximum femur length equation was applied (Fig. 7.23). No female within this sample demonstrated crural indices within the range for the 'black' reference population (83.8 ±0.5). The standard error for all these equations are much larger than those for the population specific regression formulae and therefore allow for a greater inclusion of individuals within the error range. Both females with inaccurate stature estimations from this formula present crural indices much lower than the reference population (79.83 and 77.28, respectively). The individual with the higher index (Caister-on-Sea 84) also demonstrates a torso length much shorter than the mean length within the sample. The lower index and shortened torso length does not fit with this equation's body proportions, resulting in an overestimation of stature. A few females have lower crural indices than Caister-on-Sea 84, however their torso lengths are longer, allowing the equation to use the overestimation of the lower limb length to be incorporated into the torso height and thus produce a stature within standard error. The female with a higher crural index (Apple Down 4B) displays a calculated stature that is underestimated, though within the range of standard error, by the maximum femur length equation. This female also demonstrates an elongated torso length compared to the rest of the sample. The maximum femur equation underestimates both the length of the tibia and the length of the torso.

Generally, those of African descent display shorter torso lengths in comparison to total stature, whereas those of European descent possess torso lengths that are longer in comparison to overall stature (Eveleth and Tanner, 1990). The 'black' reference population from the Terry Collection tend to possess shorter torso lengths than their 'white' counterparts. The longer torso length compared to stature of these Early Medieval females seem to lessen the impact a lower crural index will have on the calculation of stature using these equations. Unfortunately, the 'white' reference population displays not only higher crural indices than the Early Medieval female sample, but longer torso lengths. These differences in body proportions between the reference population and sample impact the accuracy of estimating stature as these linear regression cannot account for large variation from the mean.

7.2.3.2 Population specific regression formulae for Early Medieval females

When examining the formulae produced from stature estimated using the Fully anatomical method, four females from the sample of eight had their stature either over- or underestimated using one or two population specific formulae. Three females (Apple Down 4B, Caister-on-Sea 84 and 136) had stature estimated outside the standard error using the maximum length of the femur (Fig. 7.26) and summed lower limb length (Fig. 7.28), with the females from Caister-on-Sea being overestimated and the female from Apple Down being underestimated.

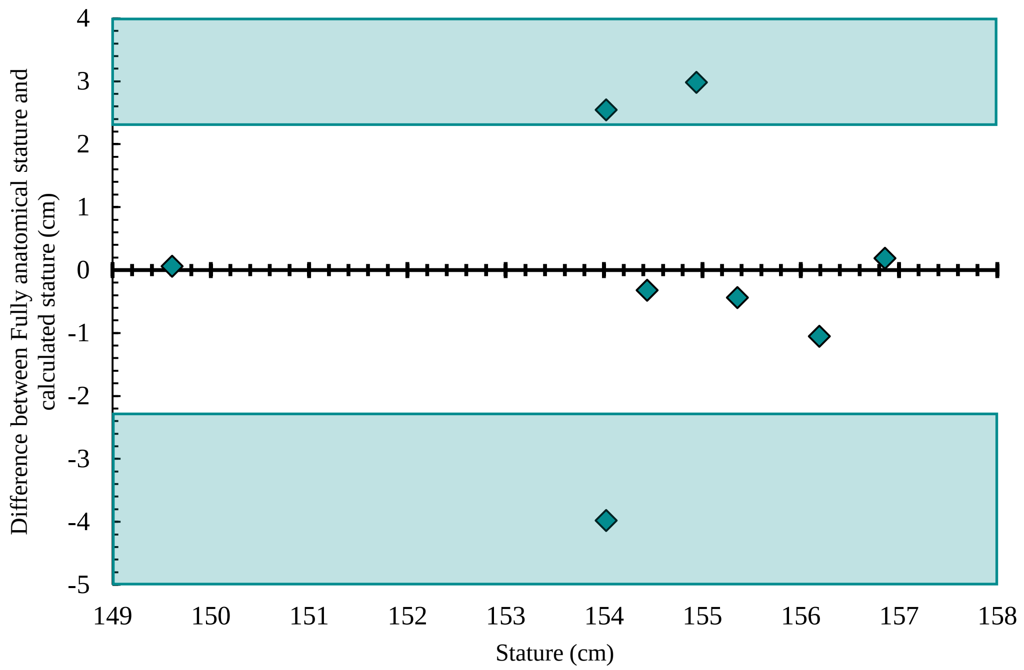


Figure 7.26: *Stature calculated using the Population specific maximum femur length formula plotted against the difference between calculated and Fully anatomical stature of Early Medieval females. Three females had stature estimated outside the standard error of the equation (±2.33 cm). These females are located within the shaded area of the graph.*

The over and underestimation of stature using the population specific formulae is due to a combination of crural indices and torso lengths that are outside the one standard deviation of the mean. For example, Apple Down 4B possesses femora and tibiae that are more equal in length and an elongated torso, thereby underestimating stature. Only one female was incorrectly estimated using both the tibia and summed lower limb length formulae: Apple Down 86 (Fig. 7.27). This individual has a crural index and torso length within one standard deviation, however the combination of these proportions do not correlate with the mean, therefore this female's stature is underestimated.

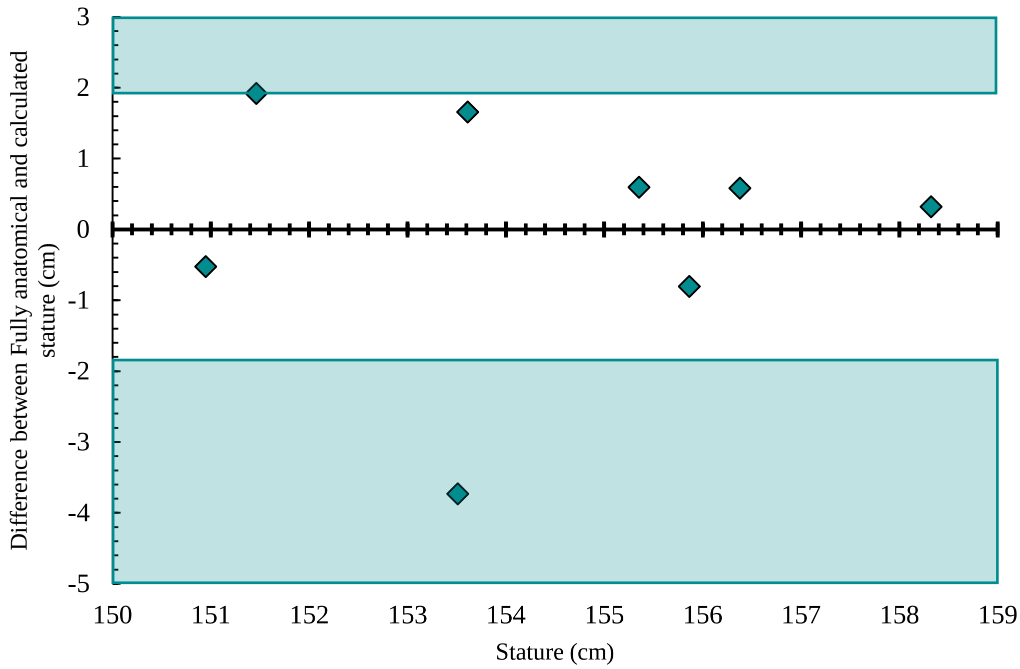


Figure 7.27: *Early Medieval female stature calculated using the population specific tibial length equation. Teal lines represent the standard error of the equation (±1.92 cm). Individuals in the shaded areas represent females whose stature was estimated outside the standard error.*

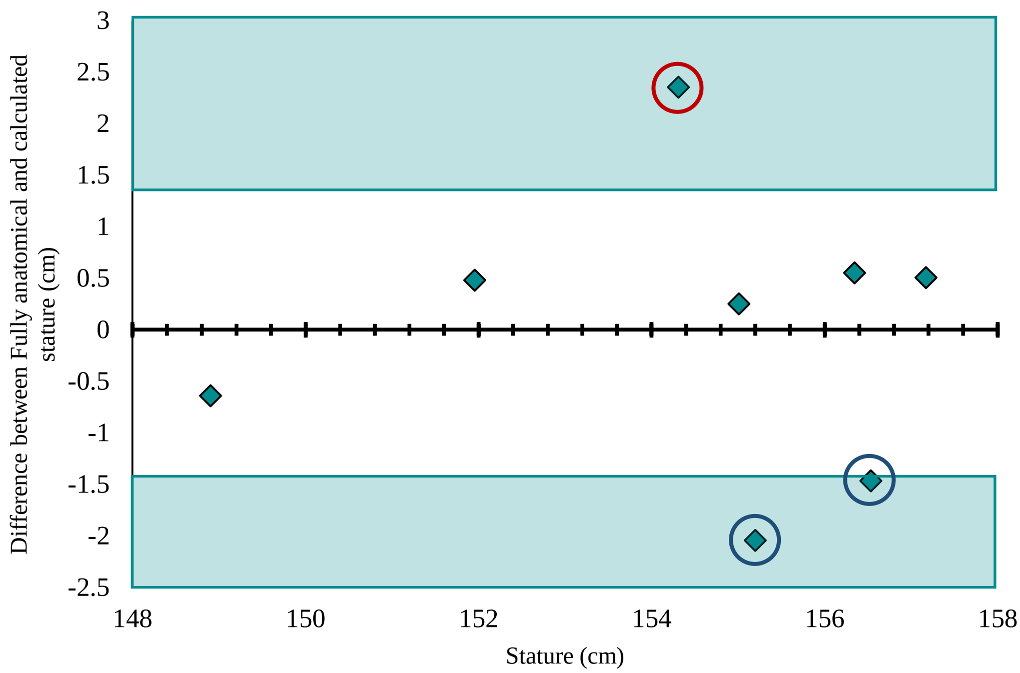


Figure 7.28: *Early Medieval female stature calculated using the population specific regression formula for summed lower limb lengths. Apple Down 86 is highlighted in the red circle and Caister-on-Sea 84 and Apple Down 4B highlighted blue circles. Standard error for the equation is ±1.48 cm.*

The presence of stress indicators was also considered to assess whether disruptions to the growth and development of the skeleton were present that could have influenced final body proportions. Another possibility of those presenting different body proportions could be due to non-local origins of individuals. Only one 'known' stature had cribra orbitalia (Apple Down 4B). This individual had an unusually high crural index (85.94), long torso (463.99 mm), and tall overall stature (158.00 cm). The female with the lowest crural index (77.28), Caister-on-Sea 136, displayed dental enamel defects indicating bouts of stress during development. Their shortened tibial length in comparison to femoral length, along with shortened torso length, could indicate environmental stress during the critical periods of growth in both the long bones (childhood) and torso (adolescence). Finally, another female from Caister-on-Sea, skeleton 84, had a stature below the mean (151.96 cm), a crural index within one standard deviation of the mean, and no skeletal indicators of stress. Their shortened stature comes from a torso length that is 1.5 cm shorter than the average female within the sample. Perhaps this female experienced stress during the adolescent period of development, a period when growth in the torso is rapid, but the child is too old for cribra orbitalia or dental enamel defects to manifest.

It is important to emphasize the role of torso length in the composite of stature. For example, Caister-on-Sea skeleton 84 had a crural index within one standard deviation of the mean for this sample; however their shortened torso length drove their stature to be shorter than was estimated using both the maximum femur and summed lower limb length formulae. The low mean PPE presented in Chapter Six demonstrates that when individuals with similar body proportions have stature estimated using the population specific equations, they produce the most reliable stature estimations of Early Medieval females out of the many published formulae.

7.2.4 Early Medieval male stature estimation

The number of Early Medieval males sufficiently well preserved to conduct the Fully anatomical method was only 16. This section discusses the accuracy of estimated stature using the regression formulae from Trotter and Gleser (1952, 1958) and Trotter (1970), as well as the population specific formulae. The effects of differences will also be explored.

7.2.4.1 Trotter and Gleser (1952, 1958) and Trotter 1970 formulae

A total of ten males had stature overestimated beyond the standard error using one, two, or all three of Trotter and Gleser's (1952, 1958) 'white' formulae. Seven males had stature overestimated using the maximum femur equation (Fig. 7.29). One male (Berinsfield 32) was overestimated using this equation only. This male presents a crural index that is lower (78.36) when compared to the mean crural index of the Terry Collection (81.9 ±0.4). Eight males had stature overestimated using the equation calculated based on tibial length (Fig. 7.30).

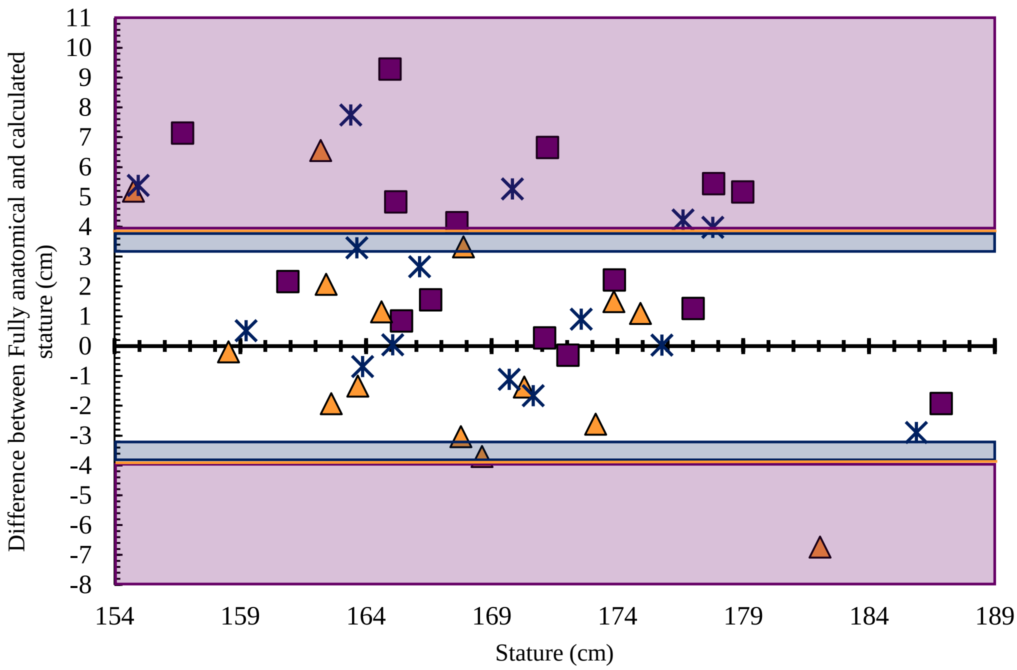


Figure 7.29: *Stature estimations using the maximum femur length equations from Trotter and Gleser's (1952, 1958) 'white' and 'black' formulae (purple squares and yellow triangles, respectively) and Trotter's (1970) 'white' formula (blue crosses). Standard errors for each equation within the purple (Trotter and Gleser's (1952, 1958) 'white' formula, ±3.94 cm), yellow (Trotter and Gleser's (1952, 1958) 'black' formula, ±3.91 cm), and blue (Trotter's 1970 'white' formula, ±3.27 cm) lines.*

Finally, seven males have had their stature overestimated using the summed lower limb length formula (Fig. 7.31). Five of these males were overestimated using all three formulae, whilst the other two were overestimated by the maximum femoral length equation (Apple Down 28) and tibial length equation (Caister-on-Sea X1). Individuals with a higher crural index tend to be overestimated using tibial length more than formulae using the maximum femur length, whilst those with a lower crural index tend to be overestimated using the maximum femur length equation more so than tibial length equations. Crural index, though playing a large role in determining the effectiveness of an equation, is not the only aspect of stature that drives differences between the 'known' and calculated stature. The mean torso lengths for the 'white' reference population within the Terry Collection are unknown to the author, however their length could be assumed to be much longer than this sample.

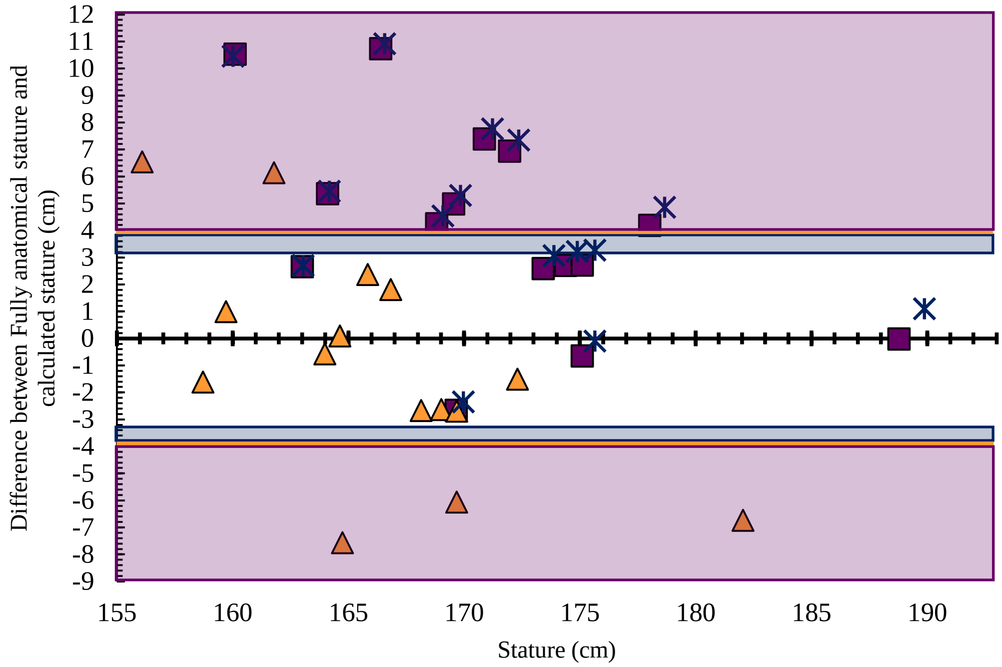


Figure 7.30: *Early Medieval male stature calculations using Trotter and Gleser's (1952, 1958) 'white' tibia formula (purple squares), Trotter and Gleser's (1952, 1958) 'black' formula (yellow triangles), and Trotter's (1970) 'white' formula (blue stars). Standard error associated with each equation denoted with purple (1958, 1958 'white', ±4.00 cm), yellow (1952, 1958 'black', ±3.96 cm), and blue (1970 'white', ±3.27 cm) lines. Those individuals within the shaded regions had stature inaccurately estimated using these formulae.*

Those males whose stature were accurately estimated by all three formulae possess elongated torso lengths compared to the rest of the sample, with none falling below 500.00 mm. This highlights the need to assess torso length when possible as not only could different crural indices estimate stature incorrectly, but differences in torso length could over- or underestimate stature as well.

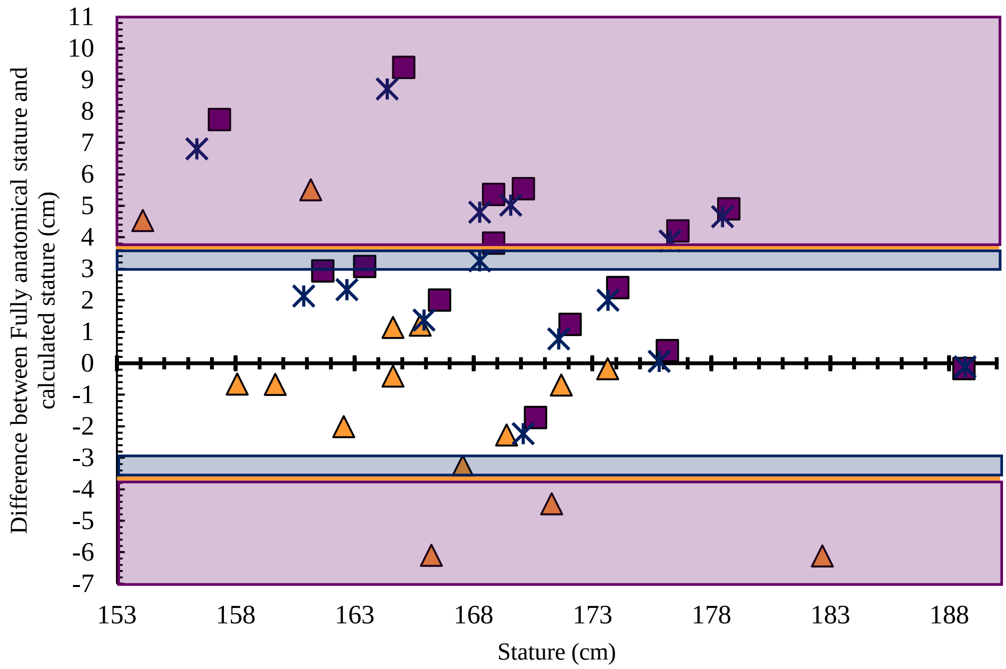


Figure 7.31: *Stature calculated using the summed lower limb length of Early Medieval males using Trotter and Gleser's (1952, 1958) 'white' (purple squares), 'black' (yellow triangles), and Trotter's (1970) 'white' (blue stars) regression formulae. Standard error for each equation is represented with purple ('white', ±3.74 cm), yellow ('black', ±3.68 cm), and blue ('white' 1970, ±2.99 cm) lines. Those males within shaded areas had stature estimated outside the standard error of their respective equations.*

Only five of the fifteen males whose stature was estimated using the Fully anatomical method were incorrectly estimated using the 'black' formulae (Fig. 7.31). Interestingly, the male who possessed a higher crural index (Abingdon 39(2443)) than the reference population demonstrated a longer torso length. This male was underestimated, whilst those two males (Apple Down 19 and Caister-on-Sea 121) possessed lower crural indices and shortened torso lengths had stature overestimated. These three males were also incorrectly estimated using both the tibia and summed lower limb length. The remaining two individuals (Buckland 385 and Caister-on-Sea 93) had stature underestimated using both tibia and summed lower limb lengths (Figs. 7.30 and 7.31). Both males had lower crural indices (79.58 and 80.46, respectively) and elongated torso lengths (530.13 mm and 520.26 mm, respectively). The lower crural index means the actual femur length is longer that what will be predicted by the formula which was created from a population with a higher crural index. This, along with longer torso lengths, produce statures which are lower than the 'known' stature. Based on the underestimation of males with longer torso lengths, the 'black' formulae may not be appropriate to estimate Early Medieval male stature, though they seem to be more accurate than the reference population used to create the 'white' formulae.

7.2.4.2 Population specific regression formulae for Early Medieval males

The population specific formulae presented the lowest mean PPE from all formulae tested within the results chapter (see Appendix 3 Table 14). Despite this low mean PPE, more males were incorrectly estimated with these formulae (eight individuals) than with Trotter and Gleser's (1952, 1958) 'black' formulae. The larger standard error encompassed in the Trotter and Gleser publication allows for a greater difference between 'known' and calculated stature, whereas the standard error range is greatly narrowed, not allowing for much error.

Six of the fifteen males were inaccurately estimated using the maximum length of the femur (Fig. 7.32). Three of these males (Caister-on-Sea 41, 122, and Apple Down 28) were incorrectly estimated using this equation only.

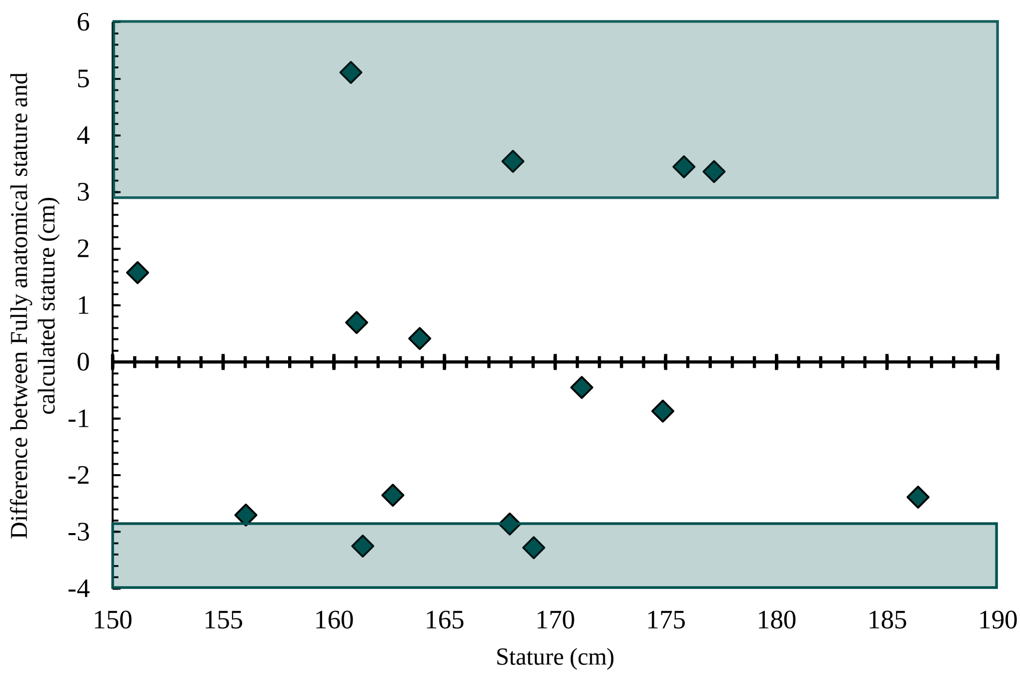


Figure 7.32: *Difference between Fully anatomical stature and population specific regression formulae utilizing the maximum length of the femur for Early Medieval males. Standard error of the equation (±2.96 cm) marked with dark green lines. Males whose stature falls within the highlighted area represent those who were incorrectly estimated using the femur length.*

The population specific equation assumes a shorter length in the tibia and produces a stature below the ‘known’ stature. The opposite is true for the two males (Caister-on-Sea 41 and Apple Down 28) who present slightly lower crural indices (80.36 and 80.21, respectively). Their crural indices demonstrate tibial lengths that are shorter than the mean when compared to femoral length. Since the equation assumes a higher tibial length to femoral length ratio, it assumes a greater overall tibial length, thus overestimates stature.

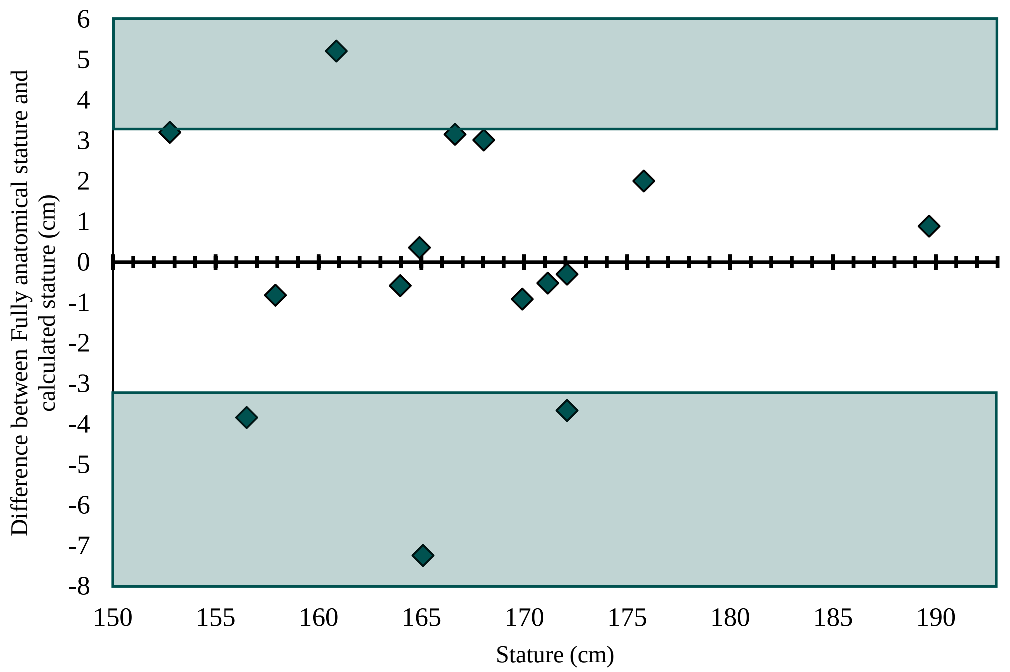


Figure 7.33: *Early Medieval male stature estimation using tibial length population specific regression formula. Differences between Fully anatomical and the calculated stature are plotted. Standard error of the equation (±3.33 cm) is highlighted with green lines. Males whose stature was inaccurately estimated are located within the shaded region of the graph.*

Four individuals were incorrectly estimated using the tibia length equation (Fig. 7.33), which were caused by lower crural indices or elongated torso lengths. Only two males (Apple Down 19 and Buckland 385) had stature incorrectly estimated using all three formulae. Both males possessed torso lengths that were outside the one standard deviation range inhibiting accurate estimation of stature using these formulae. This highlights the importance of assessing stature using the Fully anatomical method in order to better understand variability in body proportions. Skeleton 19 from Apple Down was overestimated using all three formulae and displays a final stature that is almost 15 cm below the mean stature of the Early Medieval male sample (155.65 cm vs 170.49 cm), because their torso length is extremely short. This male does not display any cribra orbitalia, however dental enamel hypoplasia was present indicating stress during childhood. Perhaps this stress was chronic and not only impacted long bone growth, but inhibited growth during adolescence. Another alternative explanation of the shortened torso length could be an individual who possess different ancestral genes than the local population. Another individual in which all three formulae were incorrect at estimating stature was Buckland 385. This male is slightly taller than mean (172.32 cm) and much of this height is due to an elongated torso (530.13). Their crural index is much lower, meaning a shortened tibial length. The presence of dental enamel hypoplasia might point to stress experience during childhood impacting the growth and development of the tibia, but perhaps this male recovered and was able to return to a normal growth trajectory during adolescence, hence an elongated torso length. To determine if these differences in body proportions and stature are caused by migration or stress experience during growth and development, isotopic analysis and/or aDNA analysis should be performed.

7.2.5 Overall trends

Female and male stature from both periods was overestimated when using the 'white' regression formulae from Trotter and Gleser (1952, 1958) and Trotter (1970), whilst slightly underestimated using the 'black' regression formulae. Differences between calculated stature and 'known' Fully anatomical stature from these samples highlight the importance of having a reference population that reflects similar body proportions to that of the sample being examined. Prior to calculating stature from single or multiple long bones, the crural index of an individual should be calculated and compared to the index of the reference population as this will aid in determining if certain skeletal elements might over- or underestimate stature. Along with the crural index, torso length must also be considered, especially since this portion constructs almost half of an individual's total stature. An individual can have a crural index that is similar to the reference population, however, stature may still be inaccurately estimated if the individual displays an unusually long or short torso. Trotter and Gleser's (1952, 1958) and Trotter's (1970) reference 'black' population contained individuals with higher crural indices than the archaeological samples analysed here. Generally, the elongated tibial length of a reference population will overestimate stature when using the maximum femoral length equation, whilst underestimating stature using the tibia equation. When considering the equation using the summed lower limb lengths, researchers must also evaluate the impact of torso length. The shorter torso lengths in comparison to lower limb lengths and overall stature of the 'black' reference population produced more accurate estimates than the 'white' formulae. The shortened torso length within the 'black' formulae is incorporated into the total stature despite these individuals possessing shortened tibial lengths (as indicated by lower crural indices) and produces a shorter stature estimation than those estimated using the 'white' formulae.

During the analysis of the population specific formulae a correlation was discovered between individuals who possessed torso lengths outside the standard deviation and the inability of the population specific formulae to accurately estimate living stature.

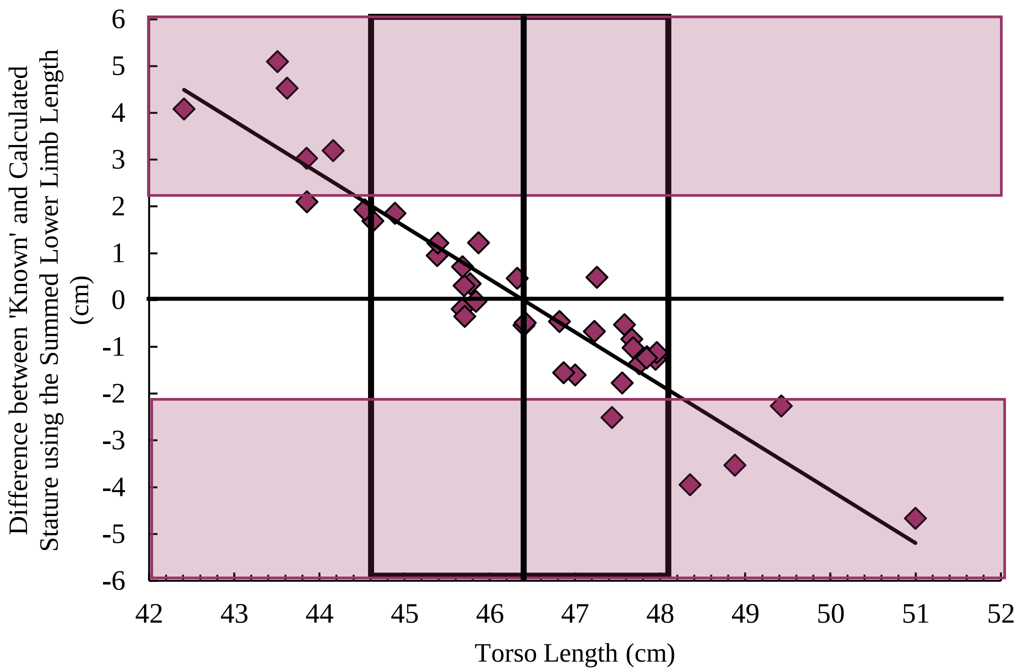


Figure 7.34: *Scatter plot of torso lengths against calculated difference between the 'known' stature and estimated stature using the population specific summed lower limb length regression formula. The shaded purple horizontal boxes represents the standard error associated with this equation (±2.19 cm) and the black vertical box represents 1 SD of the mean torso length. Mean torso length is represented with the black line.*

It was originally discovered when examining the 16 Romano-British females in greater detail (see section 7.2.1.2 this chapter). This correlation was particularly evident for both female samples. Within the Romano-British female sample, a negative correlation between torso length and difference between calculated stature and 'known' stature was discovered (Pearson's r = -0.84) (Fig. 7.34). A similar pattern was observed within the Early Medieval female sample, though the strength of the correlation was slightly lower (Pearson's r= -0.80). The Romano-British male sample followed closely with both female samples (Pearson's r= -0.88), whilst the strength of this correlation was less strong within the Early Medieval male sample (Pearson's r= -0.69). The relative torso height (absolute torso height divided by summed lower limb length) was compared to differences between the two methods of stature calculation with little correlation within the female samples (r = -0.20) and a stronger correlation within the male samples (r= -0.64).

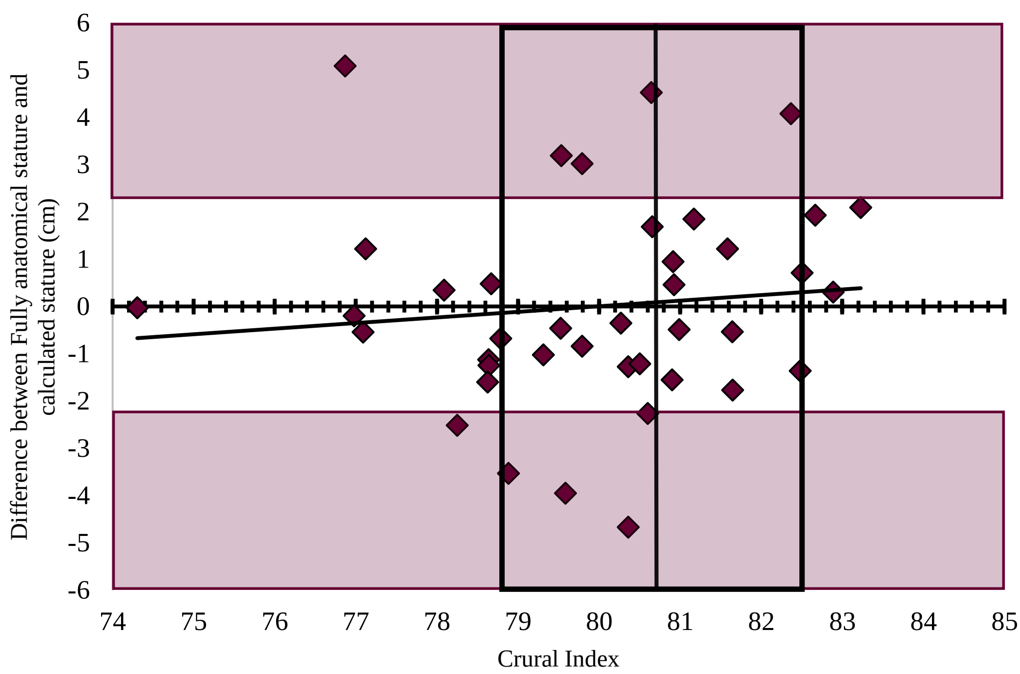


Figure 7.35: *Crural index of Romano-British females plotted against the difference between the Fully anatomical stature and calculated stature using the population specific summed lower limb length regression formula. Shaded areas represent the standard error of the equation (±2.19 cm). The black vertical box represent ±1 SD of the crural index with the black line demonstrating mean crural index.*

No correlations between the crural indices or the relative torso length versus summed lower limb length were observed (Figs. 7.35 and 7.36). It does not seem to be body shape that is driving this difference between the ‘known’ stature and calculated stature. The correlation between torso length and the accuracy of the population specific regression formulae demonstrates the importance of measuring vertebral elements when possible.

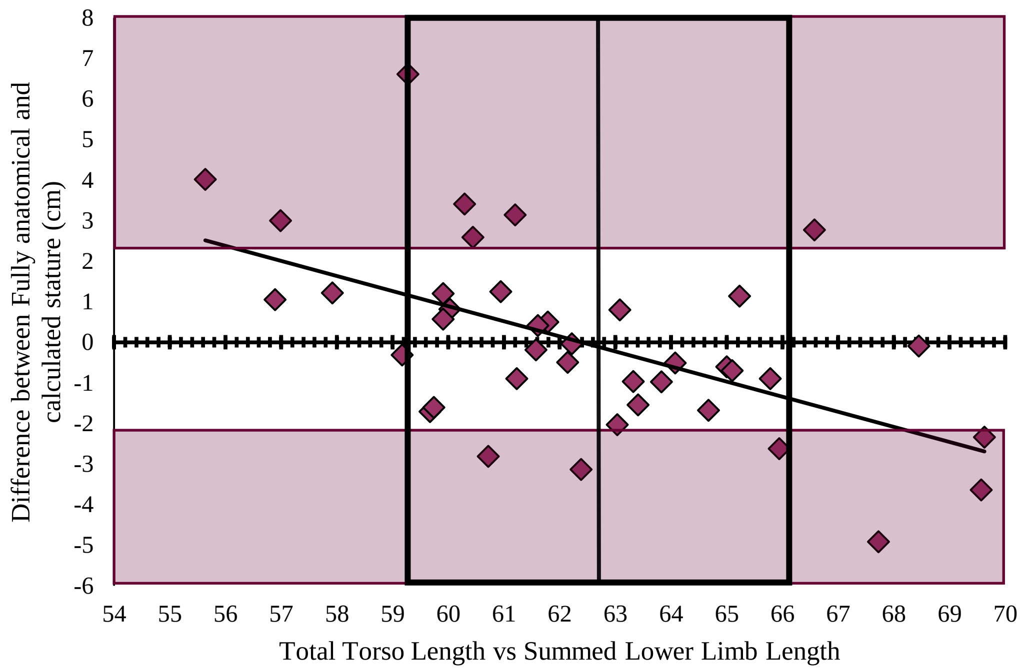


Figure 7.36: *Ratio of total torso length divided by summed lower limb length for Romano-British females plotted against difference between Fully anatomical and calculated stature using population specific summed lower limb length regression formula. Standard error of the equation (±2.19 cm) demonstrated through the shaded areas of the graph. Mean ratio represented by black central line with 1 SD of the mean marked by the black box. No significant correlation was found between this ratio and differences between stature estimation methods.*

Another interesting trend was the statistical variance in stature calculated from the three population specific formulae and crural index. Increasing distance of crural index from the mean sample index created greater differences in stature estimations between the formulae, producing a parabolic relationship (Fig. 7.37).

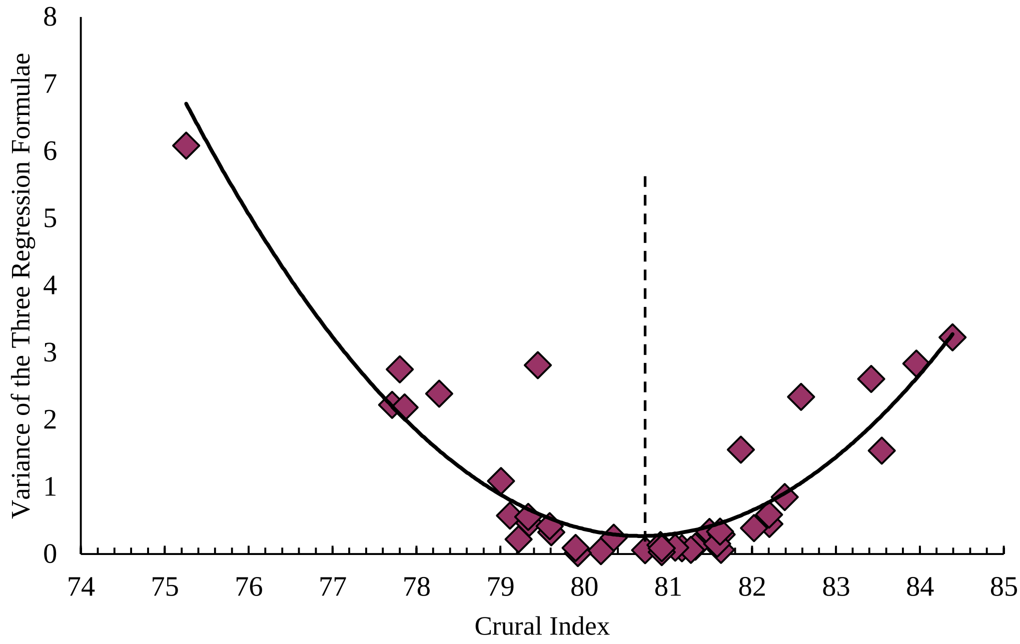


Figure 7.37*: Scatter plot demonstrating crural indices of Romano-British females and variance calculated between the difference of 'known' stature and all three regression equations. Dashed vertical line marks the mean crural index for this sample.*

This pattern was discovered in all four sample groups regardless of sex or period. The further away an individual's crural index was from the mean crural index the greater the difference in statures reported from each of the three formulae (maximum femur length, tibia length, and summed lower limb length). As illustrated in Figure 7.37, the variance in stature estimation reported does not indicate whether the calculated stature is correct, just if the reference sample and the archaeological individual have a similar crural index. To demonstrate this point, Figure 7.38 displays absolute differences between the 'known' stature and calculated stature for all three formulae and crural indices. Though the crural index does play a large role in the construction of stature, it is not the only driving force. Those individuals who demonstrate similar crural indices to the mean, but display large degrees of differences between 'known' and calculated stature most likely possess torso lengths outside the 'normal' range. The accuracy of these formulae is dependent not only on a similar crural index, but torso length as well.

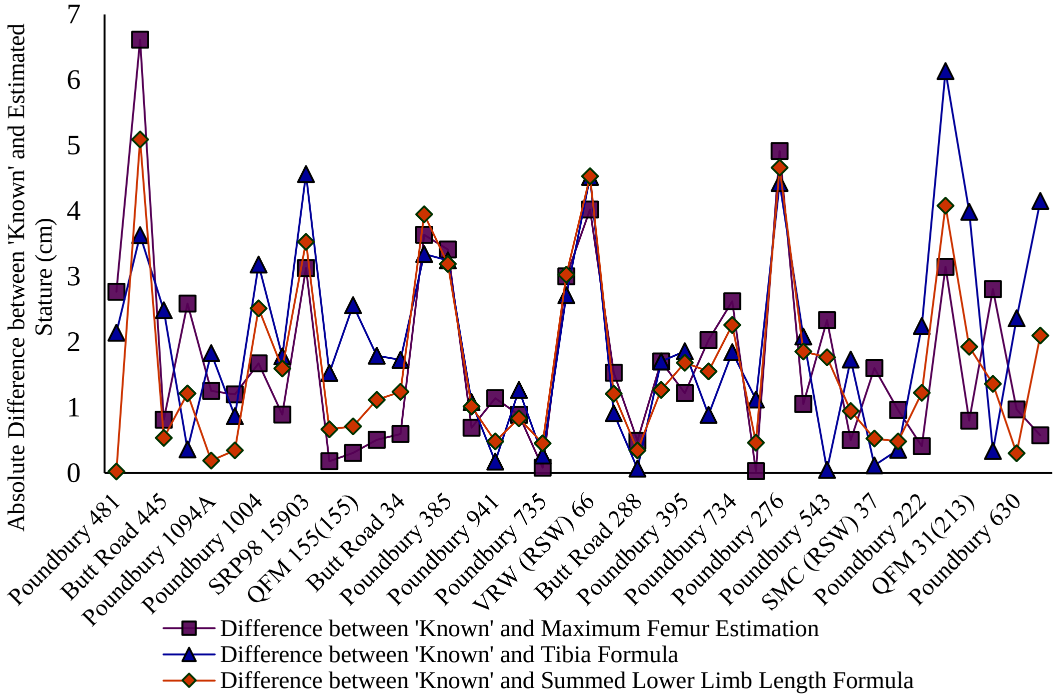


Figure 7.38: *Absolute differences between the 'known' stature and estimated stature from the maximum femur, tibia, and summed lower limb length formulae. Those females located on the opposite ends of the graph have lower (left side) or higher (right side) crural indices. These females demonstrate a higher degree of variance between each of the three formulae. Females located near the center display lower degrees of variance. Those who have a large difference between the 'known' and calculated statures most likely display torso lengths that are more different to the mean torso length.*

The recommendation by Brothwell and Zakrzweski (2004) and Goldewijk and Jacobs (2013) to compare long bone lengths as a proxy for stature to assess changes in population health will present only a partial picture. Based on long bone lengths, Early Medieval females appear to have benefitted from a 'healthier' living environment as their mean femora and tibiae are ~1.5 cm longer than their Romano-British counterparts. However, when comparing overall stature using the revised Fully anatomical method, this difference is non-existent with the Romano-British female stature mean at 154.83 cm (n=40) and Early Medieval female stature mean at 154.43 cm (n=8). Similar stature between periods is caused by the shortened torso lengths in Early Medieval females, highlighting the important role of the torso and the necessity of looking at the 'whole' individual when possible. This reveals a challenge when using mathematical regression formulae; it has difficulty accurately estimating the stature of an individual if they do not possess a similar torso length to the mean of the reference sample. It presents similar struggles as long bone length comparisons as it utilizes these long bone lengths to estimate overall stature (though the long bone lengths do not introduce estimation errors). Though there are pitfalls with the revised Fully anatomical method (see section 3.2.2.5, Chapter Three), it allows researchers to investigate the impact of the environment on the whole individual and provides a much more nuanced picture of trends in stature.

7.3 Body Proportions

Body proportions play an integral role in the calculation of stature and can be useful in the assessment of the overall health of past populations. Many researchers simply report the brachial and crural indices of a skeletal population and do not include indices that could hold valuable information such as relative torso height, relative lower limb length, and relative upper arm length versus torso height. In anthropometric studies of living populations, these proportions are routinely recorded and analysed to determine the overall health of populations (Eveleth and Tanner, 1990; Ruff, 1994; Norgan, 1998). They are used to indicate whether improvements in nutrition, access to medical treatment, clean water, and education have an impact on the growth and development of a society and if so, how much of an impact can be seen with regard to body proportions (Eveleth, 2001:137). Specifically, Katzmarzyk and Leonard (1998) emphasise the importance of looking at relative sitting height (similar to relative torso height within the bioarchaeological context) as it is shaped by nutritional resources and the surrounding environment (pg. 494). Based on the importance of these body proportions in the construction of stature and implications that could be brought forth through greater analysis of these proportions, the following section will put the body proportions of the Romano-British and Early Medieval samples into a global context using indices reported by Auerbach (2007), including information within Holliday's (1995) study of global variation.

Earlier studies of body proportions investigated correlations between climate and body shape with regard to Bergmann (1847) and Allen's (1877) ecogeographic patterns. Steegmann (2005) found that in more modern populations, variation in body proportions and stature was not as strongly correlated with climate as was reported in Newman and Munro's (1955) study of U.S. Army recruits. He explained that improved health and nutrition, along with greater mobility in the United States influenced body proportions more in the modern context than climate. However, when analyzing past populations' skeletal remains dating from various periods throughout history, climate demonstrates a larger role in the development of different body proportions. Generally, differential proportions of the body can be found and are based on whether an individual possesses African or European ancestry. For example, humans from lower latitudes generally have longer limbs relative to torso height (Auerbach, 2007). Though climate impacts an individual's overall proportions, plasticity of body proportions during development also impacts the final representation of these proportions (Eveleth and Tanner, 1990; Komlos, 1995; Karlberg, 1998; Humphrey, 2000; Stinson, 2000; Wilson, 2001; Bogin *et al.*, 2002).

As indicated in section 7.2 of this chapter, the body proportions of the Romano-British and Early Medieval females and males do not closely resemble modern populations' proportions. To analyse where these two samples fit within the wider context of the globe, brachial, crural, and intermembral indices, relative upper limb compared to torso height, relative and absolute torso lengths, and absolute lower limb length were compared to individuals from archaeological sites located throughout various regions and time periods reported by Auerbach in his 2007 thesis looking at North American variation. Within his thesis indices were compiled from various regions including those listed in Table 7.6. Females display higher relative torso heights than males within the Romano-British and Early Medieval periods, whilst males present higher indices in the rest of the categories. These differences between the sexes could be attributed to genetic variation, longer time spent in development for males, hormones, or metabolism (Auerbach, 2007:442).

Table 7.6: *Archaeological sites used in Auerbach' (2007) thesis to create regional categories for Body proportions. *Measurements from Holliday's (1995) thesis ǂMeasurements taken by Dr Christopher Ruff †Measurements from Auerbach's (2007) thesis.*

Region	**Group Measured**
Northern Europe	*The Norse (Newark Bay, Scotland ca. 1000 yBP) and Roman-British (Poundbury- ca. 2000 yBP)
Southern Europe	*European samples ((Bohemian (1000yBP), Bosnian (ca. 1000-500 yBP), St Étienne France (ca. 1000yBP), Eßlingen, Germany (1200-400 yBP))
North Africa	*Nubia (ca 1600 yBP) and *Predynastic Egypt (5000 yBP)
East Africa	ǂUganda (50 yBP)
Central Arctic	†Chesterfield Inlet, †MacKenzie District, †Sadlermiut
Western Arctic	†Aleutian Islands, †Ikogmiut, †Kuskowagamiut, †Point Barrow, †Point Hope

7.3.1 Brachial and crural indices

Overall, females and males from both periods display brachial and crural indices similar to the European or Arctic populations (Figs. 7.39 and 7.40). The Romano-British female sample falls more closely to females from the Western Arctic sample, whilst Early Medieval females align more closely with the Southern Europeans. The Romano-British males, display the same mean brachial index as the Northern Europeans, whereas the Early Medieval males are slightly closer to the Southern European mean than the Northern European mean. With regard to the crural index, Romano-British females do not fit within the European means. Their mean is similar to the indices of people inhabiting Central and Western Arctic geographic locations. The remaining three groups tend to fall between European and Arctic crural index values. These lower values demonstrate limbs more adapted to a colder environment with shortened distal segments in both upper and lower limbs.

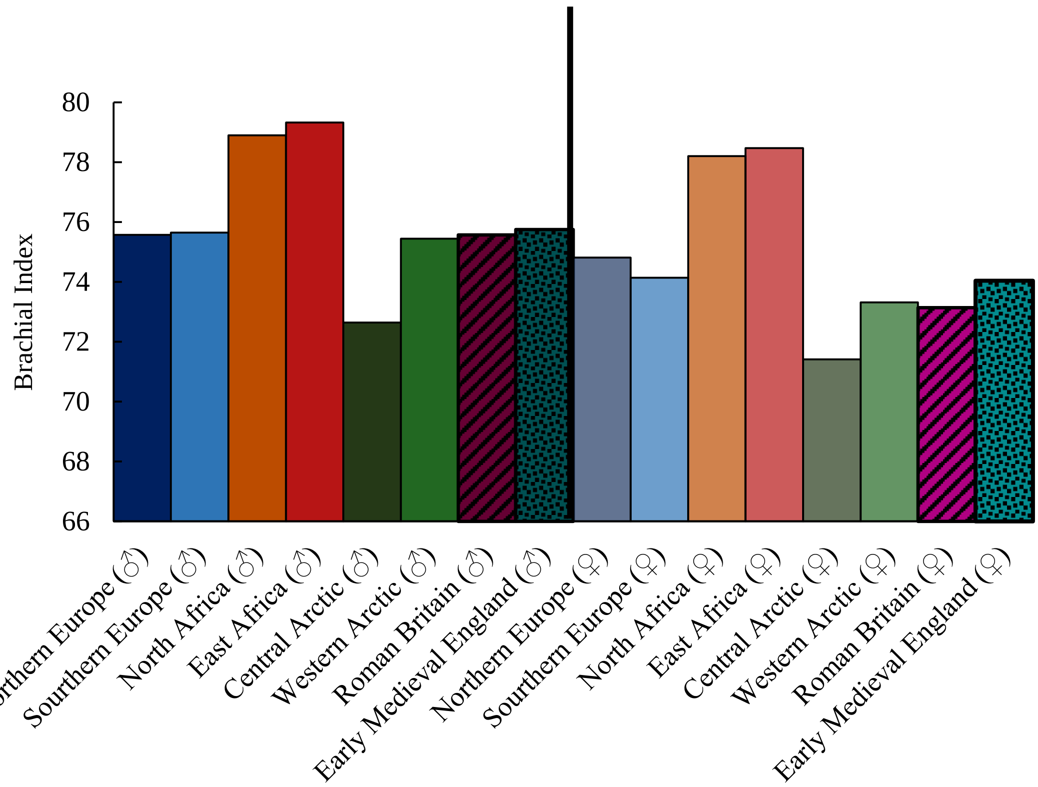


Figure 7.39: *Brachial indices from various regions throughout the world. Black vertical line separates male indices from female indices.*

However, one must also consider the impact of stress during growth and development on the final length of long bones, especially when observing the lower crural indices seen within the Romano-British female sample. An increase in both the brachial and crural indices between the two periods within the male samples was noted. With respect to the crural index, this is mostly due to an increase in the tibial length (females: 330.27 mm to 346.08mm; males: 357.71 mm to 375.70 mm) between the Romano-British and Early Medieval periods. This large increase in tibial length was not observed in the upper limb analogue (radius). The increase in distal segment of the lower limb may indicate a decrease in environmental stressors between the two periods. Numerous studies have correlated an increase in lower limb length to improved nutrition and environment (Wolanski and Kasprzak 1976; Tanner *et al*., 1982; Bogin, 1999, Bogin *et al.*, 2002). This decrease in stress experienced during childhood growth and development is also supported by the significantly lower presence of dental enamel hypoplasia within the Early Medieval sample.

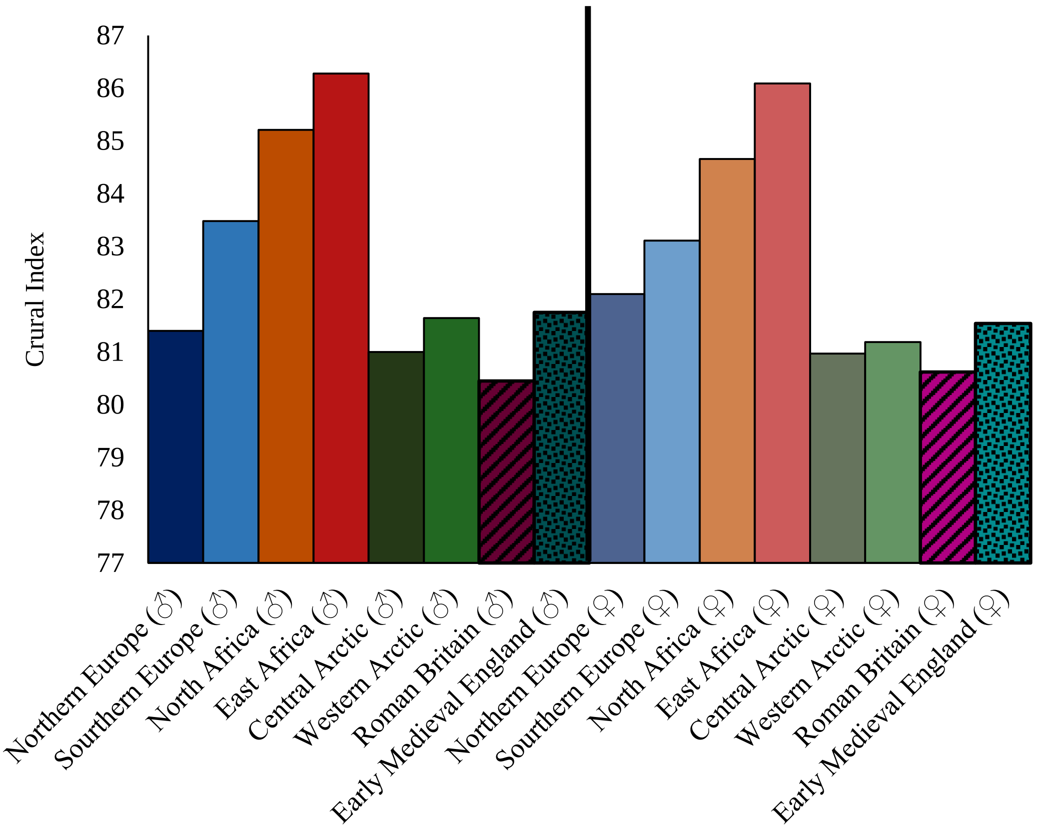


Figure 7.40: *Crural indices from various archaeological sites collected throughout the globe. Black vertical line separates male indices from female indices.*

Significant differences in the brachial index between females and males were found, whilst no significant difference was uncovered with regard to the crural index in either samples. This finding is similar to other studies on sexual differences in body proportions (Trinkaus, 1981, Ruff, 1994, Holliday and Ruff, 2001; Auerbach, 2007; Vercellotti, 2012). The difference between sexes in the brachial index could be explained by differential growth patterns of the limbs relative to one another (Holliday and Ruff, 2001; Vercellotti, 2012:195-196). Differential growth in the long bone elements of the upper limb, with positive allometry in the radius and negative allometry in the humerus (Sylvester *et al.*, 2008), and overall larger size of males in comparison to females, creates higher brachial indices for males (Vercellotti, 2012). This pattern is not found within the crural index as, based on Sylvester and colleagues' (2008) study, allometry for the femur and tibia are similar and therefore sexual differences in crural length may not be evident (Vercellotti, 2012:196). As mentioned previously, researchers must also consider environmental impacts on tibial growth within males and the possibility this may mask differences between the sexes (Vercellotti, 2012:196).

7.3.2 Body proportions involving torso lengths

Surprising patterns arose when assessing both relative and absolute torso lengths for Romano-British and Early Medieval females and males. Unlike the brachial and crural indices, greater variation is seen in torso proportions, as demonstrated by higher coefficients of variation (Table 7.7). This variation is seen with the variety of geographic locations with similar torso proportions within each sample (Figs. 7.41-7.44). For example, the mean relative torso height for the Romano-British sample falls close to those from European or Arctic populations. However, the mean for the Early Medieval sample is more closely aligned with Arctic or North African populations (Fig. 7.41). Due to their overall longer absolute lower limb lengths (Fig. 7.43) and shorter absolute torso lengths (Fig. 7.44) (which fall within the European means), their relative torso lengths are slightly lower than the Northern or Southern European means. Romano-British females and males present a more cold adapted body when it comes to intralimb indices and relative torso height, however males display absolute torso lengths much shorter than would be expected of inhabitants of Northern Europe.

Table 7.7: Coefficients of variation for each index or relative lengths.

Index	Romano-British Females	Romano-British Males	Early Medieval Females	Early Medieval Males
Brachial	2.93	2.99	2.66	2.73
Crural	2.54	2.81	2.55	2.45
Intermembral	2.99	2.92	2.69	2.36
Absolute Torso Length	4.79	4.66	3.40	5.44
Relative Torso Height	5.23	4.98	5.58	5.78
Relative Upper Limb Length/Torso Height	5.52	4.97	5.73	4.25
Relative Lower Limb Length	2.04	2.22	2.23	1.69

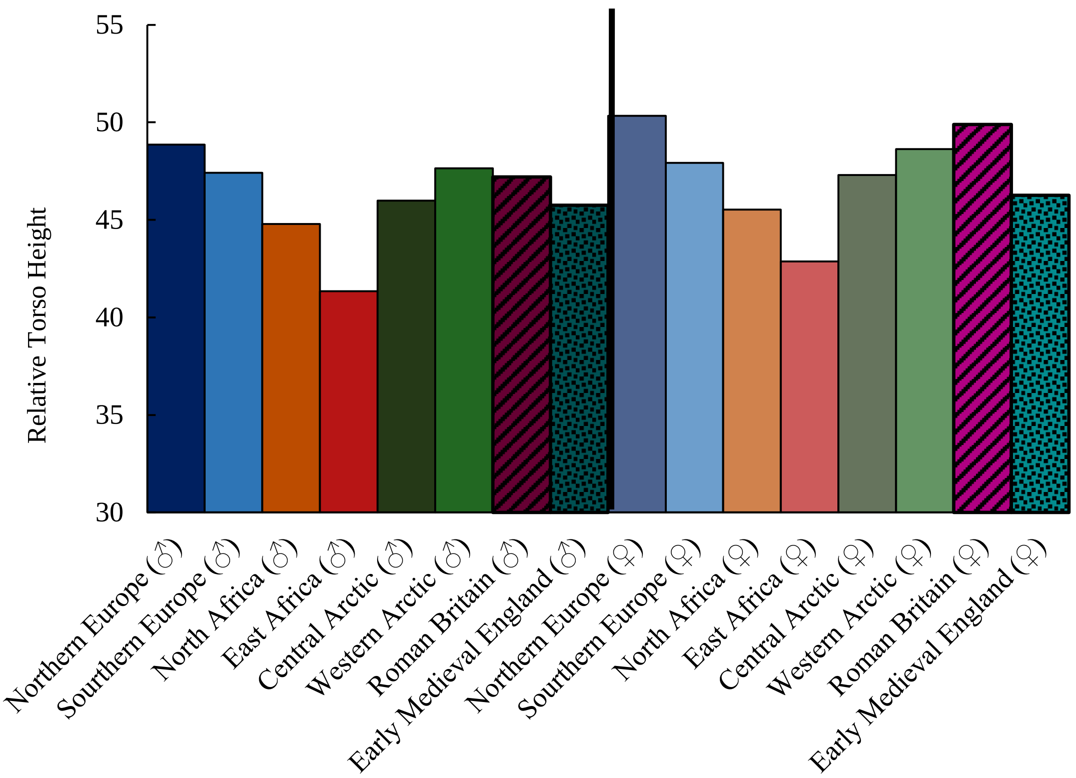


Figure 7.41: *Mean relative torso height for males and females from various archaeological sites from various geographic locations and time periods. Black vertical line separates male and female relative torso heights.*

The absolute lower limb lengths from both samples present lengths more similar to the Western Arctic (females) and Northern European (males) ranges (Fig. 7.43), thus producing relative torso heights within the more cold-adapted body proportion (Fig. 7.41). According to Vercellotti (2012), similar allometric processes may drive the differences in relative trunk height between the sexes with females displaying longer trunks relative to smaller lower limb lengths, however it may not only be due to growth, but differential development between males and females perhaps indicating stress during development of limbs (pg. 197). Auerbach (2007) concluded that climate plays a larger role in the intralimb (brachial and crural) indices, which can be demonstrated within these samples as well. Perhaps the longer lower limb lengths seen within the Early Medieval sample (Fig. 7.43) demonstrate a population inhabiting an environment that more positively promotes growth than some of the samples from Auerbach's (2007) and Holliday's (1995) dissertations. It could be that the elongated limb lengths seen within the Early Medieval sample indicate improved health from the Roman period, along with the increase in stature and decrease in skeletal indicators of stress.

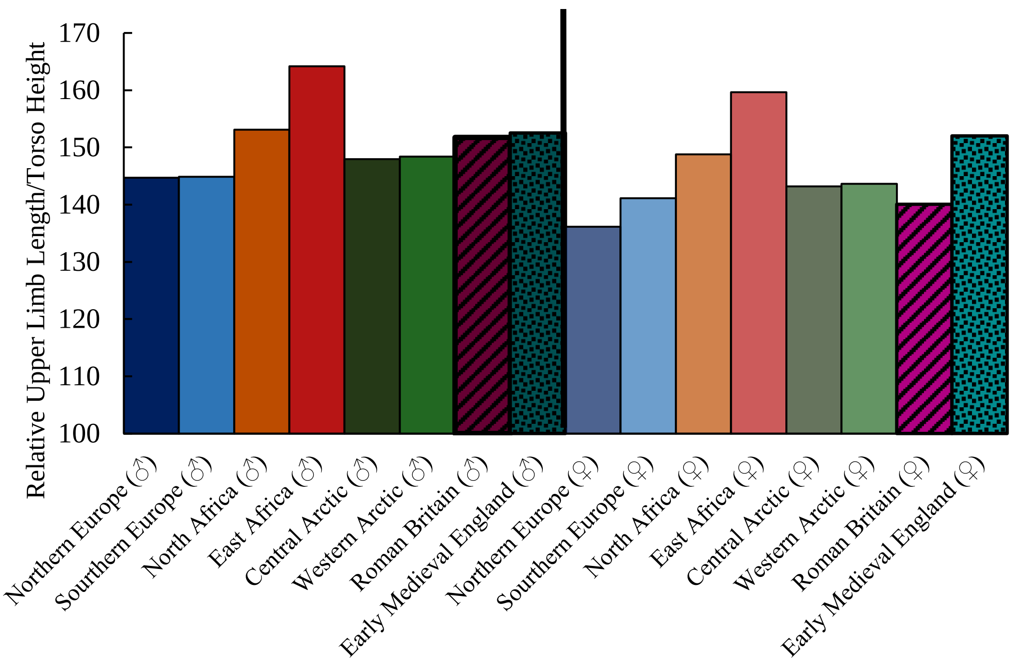


Figure 7.42: *Mean relative upper limb length/torso height for males and females from various archaeological sites locate throughout the globe and various periods. Black vertical lines separates male and female values.*

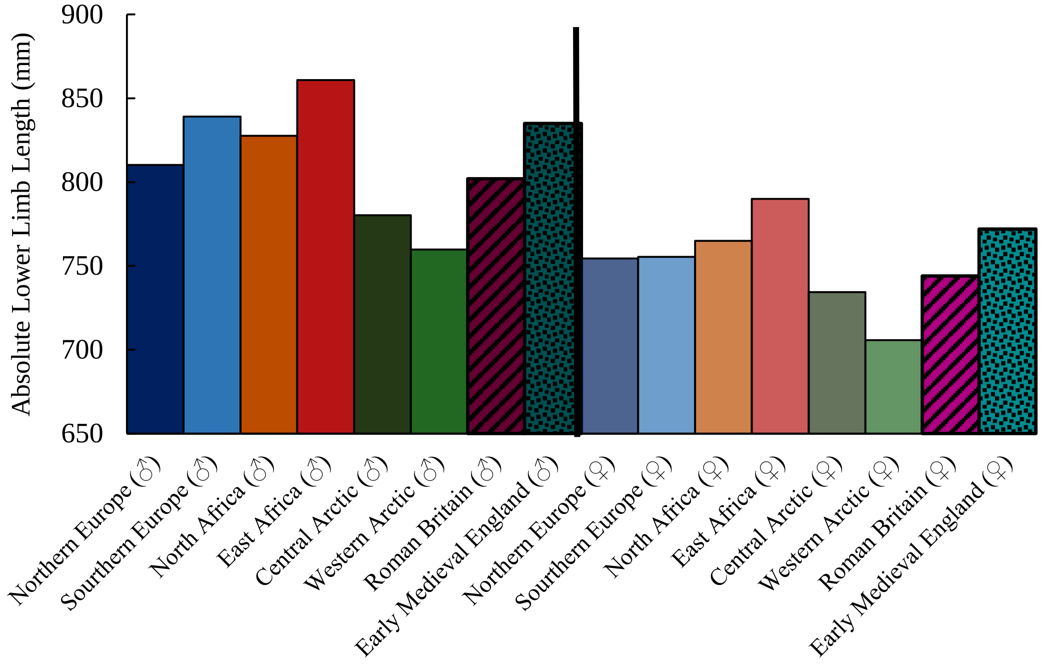


Figure 7.43: *Mean absolute lower limb length (sum of maximum femur and tibia) for males and females from Auerbach's (2007) thesis and mean measurements from Romano-British and Early Medieval sites within this dissertation. Black vertical line separates male and female lengths.*

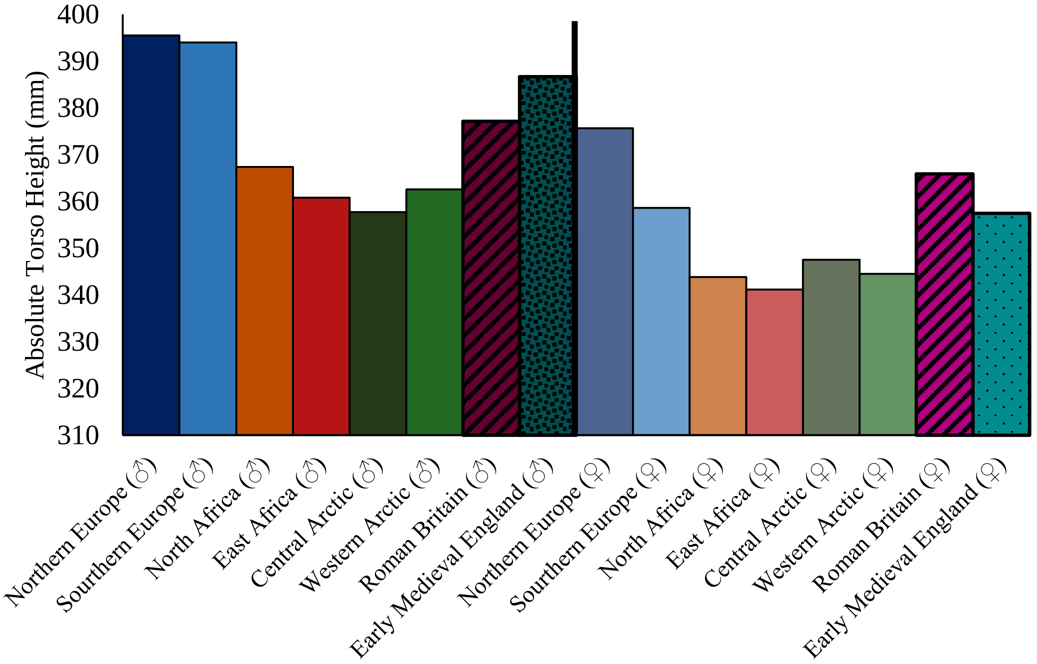


Figure 7.44: *Mean absolute torso height of males and females from various geographic locations and time periods. Mean values taken from Auerbach's (2007) thesis. Romano-British and Early Medieval values taken from this dissertation. Black vertical line separates male and female values.*

7.3.3 General trends in body proportions

It is interesting that the absolute torso length of Romano-British males is shorter than the European samples, whilst the remaining three groups (Romano-British females and Early Medieval females and males) present absolute torso lengths more akin to these European populations. Shortened torso length was discussed previously as one of the reasons that the 'white' regression formulae from Trotter and Gleser (1952, 1958) and Trotter (1970) incorrectly estimated stature when using the summed lower limb length equation. One might posit that the seemingly 'shortened' torso height of the male sample from Roman Britain could have resulted from negative factors impinging on the adolescent growth period, when growth in the spinal region is greatest. Auerbach (2007) states that we must keep in mind that resources available during development may impact overall body proportions in ways that cannot be assessed due to possible variations seen in the timing of stress experienced and the skeletal response. Not all areas of the body will be equally impacted and therefore greater variation in these proportions may arise (pg. 454). For example, Zakrzweski (2001) discovered that periods of drought and flooding within Ancient Egypt had an impact on the growth and development of long bone lengths and overall stature.

Unlike Auerbach's (2007) and Vercellotti's (2012) research on body proportions, females from both periods examined here display greater coefficients of variation in all but three indices: brachial, crural, and relative lower limb lengths. The female sample dating to the Early Medieval period, present higher CV values in crural index, intermembral index, relative lower limb length, and relative upper limb length vs torso height. Vercellotti (2012) stated that smaller variation in body proportions of the females in his study pointed to growth being more canalized for females than males, with different selective pressures on women due to the process of reproduction (pg. 204-205). Auerbach (2007) believed that the relatively small variation in his female samples compared to males supports the theory of females possessing the ability to 'buffer' negative environmental impacts during growth and development (pg. 456). Though females are known to be less developmentally plastic than males (Auerbach, 2007: 457), the greater variation seen within both female samples here makes their variation difficult to explain. Perhaps instead this points to movement within the population during both periods and therefore more variety in childhood environments/gene pool.

7.4 Historical Interpretations

The final section will place the results in archaeological context. It has been well documented that, generally, health in Britain declined from the Iron Age to Roman transition (Roberts and Cox, 2003; Redfern, 2005; Peck, 2009). This is followed by an improvement in health following the end of Roman occupation (Roberts and Cox, 2003; Arce, 2007; Klingle, 2012). The first and second subsections will look at stress indicators, stature, and body proportions within the context of Roman Britain and Early Medieval England, respectively. The final subsection will explore the transition period and its impact on general health.

7.4.1 Roman Britain

It was previously thought that the Romanization of Britain brought about positive changes for overall health through improved sanitation, hygiene, and living conditions (Mattingly, 2006:323). However, recent investigations of Romano-British archaeological sites have discovered negative impacts, including overcrowding in urban centres, increased social inequalities, and over-reliance on external sources for food (Scobie, 1986; Jackson, 1988; Dobney *et al*., 1999; Garnsey, 1999; Wacher, 2000; Williams, 2003; Morley, 2005). This decrease in overall health of the population has been noted most particularly in detailed studies of skeletal remains from the Iron Age to Roman transition in Yorkshire (Peck, 2009) and Dorset (Redfern, 2005). An increased prevalence of childhood diseases, including metabolic and dental disease, indicates the overall negative impact on children’s health during the Roman period (Redfern *et al*., 2010; Powell, 2014; Rohnbogner and Lewis, 2017). Although the analysis of childhood health was not the primary focus of this thesis, the analysis of stress indicators, stature, and body proportions presented here reveals similar findings to these studies, with higher frequencies of stress indicators found regardless of sex during the Romano-British period when compared to the later period and a putative negative impact on stature and long bone lengths than previously conceived.

This analysis of 758 individuals from various regions and settlement types (major and minor urban centres as defined by Rohnbogner and Lewis, 2017) also discovered higher rates of skeletal indicators of stress than previous analyses from this period (see Roberts and Cox, 2003) (Table 7.8). The frequency of stress indicators (cribra orbitalia and dental enamel hypoplasia) discovered within this study is more similar to that of more recent studies of Roman London by Powell (2014) and Butt Road, Colchester by Jenny (2011). A general decrease in frequency of cribra orbitalia with increasing age was noted, especially in the male sample. This trend could indicate one of two possibilities: those who are older may have had more time for the bone to remodel and thus mask the stress insult experienced during childhood development (Stuart-Macadam, 1985:393-397; Walker *et al.,* 2099:111), or those with these lesions had a compromised immune system and therefore an increased risk of frailty and inability to survive to older ages (Redfern and DeWitt, 2011).

Table 7.8: *Comparison skeletal indicators of stress analysed for this thesis and those reported in Roberts and Cox (2003) for the Romano-British population. The true prevalence rate (TRP) is presented for cribra orbitalia, whilst crude prevalence rate (CPR) is presented for dental enamel hypoplasia*

Stress Indicator	**This Thesis**			**Roberts and Cox, 2003**
	Females	**Males**	**Total**	**Total**
Cribra Orbitalia (CO)	20.6%	20.6%	20.6%	16.9% (TPR)
Dental Enamel Hypoplasia (DEH)	55.4%	58.3%	55.7%	13.5% (CPR)

This aligns with the Developmental Origin of Heath and Disease Hypothesis that early life adversity is most likely to lead to a compromised health in later life. At least half of the sample presented dental enamel hypoplasia regardless of sex (Armelagos *et al.,* 2009). Unlike cribra orbitalia, once the enamel has formed, no remodeling can occur (excluding wear), leaving a mostly permanent trace of a period of stress experienced during dental development (Ortner, 2003:595; Hillson, 2014: 201-204). A peak in DEH frequency is found within the middle age category. These lower rates seen in the older (46+ year) age category could result from dental wear and ante-mortem tooth loss obliterating evidence of early life insults, or may be due to an absence of stress experienced during dental development. Malnutrition is considered a key factor in the development of DEH, as those with malnutrition are more susceptible to infections (Hillson, 2014:193-194). Once again, the ability to recover from an episode of stress during growth and development (as indicated by the continued presence of these defects into later life) could indicate a stronger immunological response.

Males demonstrated greater variability than females with regard to long bone lengths and stature with higher CV values. These higher values might represent varied reactions to environmental stress experienced during growth and development. Smaller CV values in the long bone lengths and stature of females, along with the greater number of females demonstrating CO and DEH within the 26+ year age categories over males could demonstrates their ability to 'buffer' against deleterious environments or experiences during growth and development allowing them to survive into adulthood. Thus, stress experienced during childhood also impacts the growth of different skeletal elements. The assessment of body proportion has the ability to inform researchers about potential disruptions in growth throughout development (Pomeroy *et al.,* 2012; Gowland, 2015).

Variation seen in body proportions is mostly independent, indicating that not all elements respond to environmental factors consistently (Auerbach, 2007:444-445). Romano-British females present a mean crural index that is higher than males, meaning that females possess longer tibiae than males when compared to overall femoral length. It has been discovered that length of the tibiae in males is highly influenced by environmental factors (Holliday, 1997a, 1999; Jantz and Jantz, 1999; Holliday and Ruff, 2001; Bogin *et al*., 2002; Temple *et al*. 2008; Ruff *et al.,* 2012). This shortening of the distal segment of the lower limb is not only observed in the crural index, but also in the intermembral index. Romano-British males present a higher index than females, indicating 'elongated' upper limbs compared to lower limbs. The difference between females and males with regard to upper limb lengths is much smaller than the difference seen in the lower limb lengths, therefore the higher index in males may not be caused by 'elongated' upper limb lengths, but shortened lower limb lengths. Not only are the crural and intermembral indices different between females and males, but the relative torso height also presents statistically significant differences. Romano-British females' present elongated torso lengths compared to lower limb lengths, especially compared to their male counterparts. Perhaps the shortened lower limb lengths, shortened torso length, and higher frequency of DEH seen in the male sample represent stress experienced not only throughout childhood, but during adolescent development. While females possess shorter lower limb lengths in comparison to torso height, their greater crural index, lower prevalence of DEH, and higher relative torso height point to their ability to be 'buffered' from these deleterious environments, and thus continue to steadily grow throughout childhood and adolescent development.

According to Garnsey (1991:43-61), malnutrition was endemic in children throughout the Roman Empire. Despite wide varieties in food sources available and consumed by these populations (as evidenced by isotopic analysis) the quality and quantity of these resources cannot be determined (Powell, 2014:257). Redfern and DeWitte (2011) found an increased frailty risk during the Roman occupation of Dorset with urbanization, migration, and change in diet negatively impacting children's health. This is echoed in Rohnbogner and Lewis (2017), with higher prevalences of tuberculosis and vitamin D deficiency found within the non-adult population at Poundbury than other 'urban' contexts (pg. 222). Interestingly, children from 'rural' settlements seemed to present higher frequencies of vitamin C and cribra orbitalia than their 'urban' counterparts, indicating 'rural' habitation may have negatively impacted children's health with regard to diseases of deficiency (Rohnbogner and Lewis, 2017: 222).

The use of skeletal stress markers and isotopic studies has been used to identify possible non-locals in Roman London (Gowland and Redfern, 2010; Montgomery *et al*., 2010; Redfern *et al.,* 2016; Shaw *et al.,* 2016). It was not just adults that migrated to Roman Britain (Chenery *et al.,* 2010, Eckardt *et al*., 2014). According to Gowland and Redfern (2010), rates of CO and DEH from London are similar to the rates seen in Rome, therefore could reflect a childhood spent in a different urban centre (pg. 30). Migration to Roman London from other areas of the empire has been proven based on macromorphoscopic analysis and oxygen isotope ratios indicating migrants from southern Mediterranean locations (Redfern *et al*., 2016, 2017), as well as lead isotopes (Shaw *et al.,* 2016). It was originally reported that higher frequencies of stress indicators were seen in urban centres as it was believed that increases in population density and interconnectedness with major Roman roads between these larger urban centres would increase the number of pathogens introduced to these communities (Mattingly, 2006: 264). The greater value in sexual dimorphism in individuals from the minor urban site of Queensford Farm/Mill corroborates this hypothesis as males demonstrate greater stature compared to females, while those from Roman London and Butt Road present lower values of sexual dimorphism. However, more recent studies of human skeletal remains are revealing the negative impact that rural living had on children as many suffered from diseases caused by deprivation (Rohnbogner and Lewis, 2017:208). Larger percentages of individuals present these stress indicators, which may not necessarily indicate poorer health per se. Researchers need to be conscious of the osteological paradox (Wood *et al.,* 1992), which emphasizes that adults with these skeletal indicators lived long enough to produce skeletal lesions or marks on the skeleton indicating a strong immune system that enabled them to live long enough for these markers to develop. Whilst it is not possible to consider the levels of stress experienced in rural communities within the context of this study (which focused purely on urban centres), it can nevertheless be stated that overall health was compromised for many individuals within this period of history, and therefore within this study sample.

7.4.2 Early Medieval England

There is a great deal of debate about the extent of population migration to Britain during the post-Roman period. It was originally hypothesized that there was a large-scale influx of migrants from the continent, who replaced the native population, but this has been largely revised (Higham, 1992; Dark, 2000). Instead, a new theory of acculturation of native Britons in the face of smaller numbers of Germanic incomers (Lucy, 2000). The idea of acculturation supports the theory that climate change (flooding of rivers and encroachment of seas), as well as social, religious, and political upheaval of native lands led to the migration of people from the continent to England (Higham, 1992; Hills, 1999; Dark, 2000). Those migrating to England included individuals from northern Germany and southern Scandinavia (Simmons, 2001). Traditionally, different groups were thought to have settled in specific geographic locations throughout eastern and southern England; Angles inhabiting East Anglia, Midlands, and Northumbria; the Jutes occupying regions in Kent, Hampshire, and the Isle of Wight; and finally Saxons settling in Sussex, Wessex, Essex, and Middlesex (Williams, 1996). In reality, the pattern of migration, both to Britain and within the country, is likely to have been more fluid than this.

It was originally believed that a decline in the quality of life occurred between the Romano-British occupation and Early Medieval periods, with material culture demonstrating less refined craftsmanship (Klingle, 2012). However, new evidence from archaeological sites points to smaller, self-sufficient settlements usually comprising just three or four families (Drewett *et al*., 1988; Scull, 1993; Härke, 1997:139; Simmons, 2001), with a diet of mostly agricultural staples including bread, eggs, flour, cheese, porridge, milk, and water (Hagen, 1992, 1995, 2006). Human remains recovered from Early Medieval cemetery contexts support the idea of improved living during this period as evidenced by increased stature and a decrease in dental disease (Roberts and Cox, 2003; Jakob, 2004; Arce, 2007; Klingle, 2012). The assessment of overall health was not the primary aim of this thesis, however a decrease in the overall frequencies of dental enamel hypoplasia, increase in long bone lengths, increase in stature, and differing body proportions point to a generally improved life experience (see below for a consideration of migration).

The analysis of 490 individuals from 15 different Early Medieval cemetery sites observed similar frequencies of cribra orbitalia and a higher prevalence of dental enamel hypoplasia than those presented in Roberts and Cox's (2003) from compiled osteological reports of various cemetery sites throughout England dating to Early Medieval England (Table 7.9).

Table 7.9: *Comparison skeletal indicators of stress analysed for this thesis and those reported in Roberts and Cox (2003) for the Early Medieval sampling. The true prevalence rate (TRP) is presented for cribra orbitalia, whilst crude prevalence rate (CPR) is presented for dental enamel hypoplasia*

Stress Indicator	**This Thesis**			**Roberts and Cox, 2003**
	Females	**Males**	**Total**	**Total**
Cribra Orbitalia (CO)	22.3%	23.0%	22.7%	22.3% (TPR)
Dental Enamel Hypoplasia (DEH)	33.6%	36.2%	34.9%	18.8% (CPR)

The frequencies reported from this publication include sites dating from the 5th through 11th Centuries AD, dates beyond those studied here. In contrast to what was seen within the Romano-British sample, there is a decrease in the prevalence of cribra orbitalia between the age categories in the female sample and not the male sample. The consistent prevalence of CO in the male sample could demonstrate a lack of environmental stressors during growth and development, or perhaps those who were adversely affected did not survive past 18 years of age. The areas with the highest prevalence of CO within this period tend to cluster in the southern and eastern regions of England (Hampshire, Apple Down, and Eastern regions). The greatest prevalence of females with CO was found at sites located within the Hampshire regions, whilst males buried at Apple Down present the highest frequency in the male sample. Gowland and Western (2012) discovered an increase in prevalence of this stress indicator within the eastern and southern regions of Britain of skeletal remains dating to this period, with which no correlation could be seen in dental enamel hypoplasia. Reasoning for this higher prevalence of CO could be due to climatic changes and the flooding of wetland or marshland areas increasing the prevalence of malaria (Gowland and Western, 2012:309). Therefore, it could be possible that these higher frequencies in these regions found within this thesis could be associated with increase prevalence of malaria.

Overall frequency of dental enamel hypoplasia for the total sample was twice that reported in Roberts and Cox (2003) (see Table 7.9). This greater prevalence could be caused by the smaller period analysed for this thesis (5th-8th Centuries AD) or variation in the recording of DEH by different osteologists. Rates of DEH remained fairly consistent for both females and males, however there is a slight decrease in the prevalence of this stress indicator between the middle (26-45 years) and older (46+ years) age categories. As previously mentioned, when assessing these indicators, researchers always consider the influence of the osteological paradox (Wood *et al*., 1992). The larger number of individuals with DEH in the middle age category could demonstrate the ability of these individuals to survive into adulthood, whereas those without these indicators in the oldest age category may not have experienced lasting consequences of stress, thus allowing them to live longer. As mentioned in section 7.4.1, perhaps these older individuals present lower frequencies in DEH due to possible obliteration of evidence of early life stressors from dental wear or ante-mortem tooth loss. Higher rates of females with DEH were discovered in all regions except Oxfordshire and Apple Down. Interestingly, these two regions also demonstrate the greatest prevalence of these indicators within the male sample. Males from Apple Down demonstrate higher frequencies of both CO and DEH indicating a greater amount of childhood stress experienced, whereas females may have been able to 'buffer' these experiences or did not survive into adulthood.

The increase in stature for both males and females during this period (Roberts and Cox, 2003) has been attributed to an influx of new genes, and/or a stabilization in food resources (Arce, 2007:330). Specifically, some believe that the stature of Early Medieval females was greater than modern British females therefore showing that greater equality between the sexes existed during this period (Hollis, 1992:10). This slight increase in stature could demonstrate the social recognition of women during the Early Medieval period, which saw women landowners and involvement in public affairs (Hollis, 1992, Bitel, 2002), whereas Roman society was more hierarchical and patriarchal (Harlow, 1998:55; Grubbs, 2002). Increased ability to participate in society may have afforded women greater access to those resources previously off limits to females (Bitel, 2002). However, despite these claims, stature of females within this period only increased slightly (Romano-British: 154.79 cm and Early Medieval: 156.16 cm). Within this study females from Apple Down presented the shortest mean stature of the total sample, a stature more akin to females from the previous period. The increase in stature between males though, was confirmed through the more accurate estimation of stature using the Fully anatomical method. Though no statistically significant differences in female or male stature could be found between the sites and regions studied, a larger difference in stature between females buried within Kent and those at Apple Down was noted, whilst males at Apple Down tended to be taller than males from the later dated Eastern sites. Surprisingly, Apple Down demonstrated the shortest females and tallest males, producing the greatest sexual dimorphism seen within this sample. Greater sexual dimorphism in stature within the Oxfordshire sites was also noted. It has been shown that greater sexual dimorphism usually indicates a healthier population, or at least a population where the males are not subject to harsher environments (Eveleth, 1975:35; Bharati, 1989: 530; Gustafsson *et al*., 2007). However, both males from Apple Down and Oxfordshire demonstrate higher frequencies of dental enamel hypoplasia. In spite of early life stress experienced during dental development, these males were able to recover and continue to grow.

The long bone lengths and indices present similar conclusions, especially in regard to male health at Apple Down. Females from the sites within Kent possessed longer femora than any other region, which contributed to their greater overall stature, however their shorter tibiae length produced a lower crural index. Lower crural indices could demonstrate stress experienced during the development of the distal segment or perhaps indicate a sample with different body proportions. Males from Apple Down displayed elongated lower limbs, higher crural indices, and greater relative lower limb lengths indicating fewer growth disruptions compared to other sites. Greater lower limb lengths contributed to their increased stature over other sites, however they possessed the shortest absolute and relative torso heights. In their analysis of the Late Saxon remains from North Elmham, Wells and Cayton (1980) stated that males may have experienced greater growth disruptions after the age of 12 years as this was the threshold of childhood and the period in the life course where they began participating more as an adult within the community. Perhaps upon entering this period, delimited as 11-15 years by Stoodley (2000), stress experienced impacted adolescent growth, which occurs mostly within the vertebral column during this period of growth (Tanner, 1981; Bogin, 1999). It is currently unknown whether these shorter torso heights are caused by genetically determined body proportions or due to growth disruptions during adolescence.

By the end of the 6th Century the 'Anglo-Saxon's' (whomever they may be) controlled the majority of England, (Lucy, 2000; Wilson, 2003:29). Furnished burials, with the inclusion of grave goods, including weaponry, pottery, food and drink, and jewellery, were common in the fifth and sixth centuries (Lucy, 2000), until the 7th and 8th Centuries AD, in favour of unfurnished inhumations (Härke, 1990, 1992; Lucy, 2000). The people of this period were not a homogenous group (Drewett *et al.* 1988) and included people from throughout the continent (Higham, 1992; Hills, 1999; Dark, 2000). Smaller settlements and integration with natives through intermarriage demonstrate cooperation between migrants and locals (Scull, 1992; Welch, 1992:11; Hills, 1999). Härke's (1990, 1992, 2005) study of weapon burials from 47 cemetery sites across England stated that males whose inhumation included weaponry as grave goods did not demonstrate 'warrior graves', but individuals who were ethnically Germanic, as these males tended to have a taller overall stature and yet possessed similar frequencies of DEH as males buried without weaponry. This view of weapon burials may be over simplistic. Lucy (2000) notes that designating ethnic origins based on stature differences between weapon and non-weapon burials is problematic, especially since the errors associated with the stature formulae used by Härke would encompass the perceived differences in stature (pg 74). As presented in section 7.2 (this chapter), the use of stature formulae created from a reference population exhibiting different body proportions can lead to erroneous stature estimations and therefore lead to inaccurate conclusions. In an isotopic study of migration at Berinsfield by Hughes *et al*. (2014), only one individual possessed isotope ratios indicating origins from the continent, whereas the remaining individuals displayed ratios from within England rather than externally, which the authors argue supports the theory of acculturation rather than replacement (pg. 81).

Improvement in male health is demonstrated through decreased prevalence of DEH, increased stature, increased crural index, and increased relative lower limb length. Though there was a decrease in the prevalence of DEH, an increase in stature, and an increase in relative lower limb length, impact from this improved environment was not as drastic as it was for males. The increase in lower limb length, especially the increase in the distal segment (tibia) points to an overall improvement over the Romano-British sample. Modern studies have found that increases in tibial length occur when environmental stressors are decreased (Tanner *et al*., 1982; Bogin *et al*., 2001:208; Bogin, 2012b:349). It is possible that migration of peoples from the continent would have brought new infectious diseases and adaptation to different environments (Drewett *et al*., 1988; Welch, 1992; Williams, 1996). For example, the males at Apple Down present some of the highest frequencies of stress indicators from all sites examined, yet their taller stature seem to contradict this experience.

7.5 Chapter Summary

This chapter has discussed the results of stature and body proportion calculations within the context of Roman Britain and Early Medieval England. Critical analyses of the utilization of regression formulae to calculate stature from human skeletal remains were made with the proposal of employing the anatomical method of calculating stature when possible. Specifically, regression formulae created from modern reference populations do not accurately reflect body proportions seen in past populations and therefore caution should be used when estimating stature from human skeletal remains. Fluctuations seen within lower limb and torso heights have resulted in inaccuracies in the estimation of stature from regression formulae. Those individuals outside of one standard deviation of mean crural index and mean skeletal torso height will reduce the accuracy of stature estimations. Lower brachial and crural indices placed these samples within the more ‘cold-adapted’ body proportions seen in Arctic populations, however, with the increased prevalence of stress indicators seen within these samples (especially within the Romano-British sample) one must consider the possibility of shortening of distal segments of the limbs due to environmental stressors as a plausible cause to these lower index values. When placed into social and environmental contexts, evidence for the increase in stature (for males) and elongation of lower limbs (both females and males) seen within the Early Medieval sample indicate a healthier lifestyle than that experienced during the Romano-British period. Interestingly, Early Medieval females demonstrated an increase in lower limb lengths with a decrease in torso height compared to the Romano-British coutnerparts, causing similar mean stature between periods. Shortened stature and lower limb length, along with increased prevalence of skeletal stress indicators reveal the negative impact of the Romanization of Britain, with larger urban areas, importation of food sources, and constant migration spreading new pathogens across the island population. More evidence of the deleterious impact of the Romanization of Britain has been discovered through this assessment of stature, body proportions, and skeletal indicators of stress.

Chapter Eight: Conclusions, Limitations, and Future Directions

8.1 Research Aims

The original aims of this thesis were to calculate stature using the Fully anatomical method on a large skeletal sample dating from the Romano-British and Early Medieval periods in England and to critically examine the accuracy of frequently cited stature formulae utilized on skeletons from these periods. It also aimed to create new population specific regression formulae that would reflect the body proportions of individuals dating to these periods. Body proportions were also considered in this analysis, with the specific aim of comparing females and males from both periods. Finally, the analysis of stature and body proportions, along with the assessment of skeletal indicators of stress aimed to contribute new information about the growth, development, and overall health of adults from these periods from a range of geographic locations within England. The results support an improvement in environmental surroundings (nutritional, smaller agricultural communities, etc) during this transitional period. The subtle differences in female stature and body proportions between the two periods does not necessarily correlate with the notion of a large influx of migrants. Though there was a marked increase in stature in males between the two periods, it would be difficult to assess whether this was caused by incoming Germanic migrants, or was it due to a general improvement in health. To explore this more fully, isotopic and aDNA analysis on these samples must be conducted. Each of the original research questions will be revisited to determine whether these aims have been met.

8.2 Research Questions

1. **Which commonly used regression formulae for estimating stature (Pearson, 1899; Breitinger, 1937; Dupertuis and Hadden, 1951; Trotter and Gleser, 1952, 1958; Allbrook, 1961; Bach, 1965; Trotter, 1970; Olivier *et al.* 1978; Černy and Komenda, 1982; Ross and Konigsberg, 2002; Hauser *et al.*, 2005; Vercellotti *et al.*, 2009) is most accurate in predicting living stature in Roman and Early Medieval populations throughout the south and east of England?**

Many existing skeletal reports for this period will have overestimated stature. Specifically, the most frequently referenced publication, Trotter and Gleser's (1952, 1958) 'white' formulae, consistently overestimated stature using the maximum femoral length, tibial length, and summed lower limb length measurements, for both females and males in the Romano-British and Early Medieval periods. Due to differences in body proportions established in this analysis, especially the crural index and absolute torso length, the majority of these formulae were unable to accurately estimate stature. For Romano-British females and males, stature was generally overestimated when using maximum femoral length formulae, or underestimated when using the length of the tibia and summed lower limb length. Overall, Trotter and Gleser's (1952, 1958) 'black' formulae produced the most accurate estimation of stature for both samples, as evidenced by lower mean PPE. This conclusion does not apply to the Early Medieval sample. When estimating stature for Early Medieval females, the existing formulae with the lowest mean PPE were Pearson (1899) and Olivier *et al.* (1978), whilst Early Medieval males had stature most accurately estimated using Pearson (1899) only. These results highlight the need to estimate stature using the Fully anatomical method or population specific regression formulae, as it was expected that the reference population from Trotter and Gleser's (1952, 1958) and Trotter's (1970) would most likely reflect body proportions of these two past populations.

2. **Will population specific regression formulae created from reconstructed living stature of Romano-British and Early Medieval individuals be more accurate in predicting living stature than regression formulae used in current literature?**

When comparing stature estimations calculated using the population specific regression formulae created using the Fully anatomical method to existing formulae the results were usually more accurate. Trotter and Gleser's (1952, 1958) 'black' formulae inaccurately estimated fewer individuals outside the standard error associated with their respective equations than the population specific regression equations. However, the standard error associated with the population specific regression equations is much smaller than error calculated with the 'black' formulae. The smaller standard error associated with the population specific formulae allows for a greater number of individuals to be estimated outside this range. Those individuals who were not accurately estimated using the population specific formulae were determined to have body proportions outside the 'norm'. Fluctuations in both the crural index and torso length within these outliers emphasizes the important role of body proportions in the estimation of stature. It is recommended that the application of the Fully anatomical method be used when possible to estimate stature, as regression formulae do not have the ability to account for these fluctuations, especially with regard to torso length. If not enough skeletal elements are present or well preserved, then the population specific regression formulae should be utilised when analysing remains that date to either of these periods.

3. **Will individuals dating to the Romano-British and Early Medieval periods present different body proportions? If a difference in body proportions between these two samples is detected, where does this change occur, e.g. lower or upper limbs, distal segments of limbs (radius and tibia), or vertebral column?**

The increase in stature between these two periods, especially within the male sample, has been unequivocally established here using the anatomical method. This is the first time that the role of body proportions in the construction of stature has been comprehensively analysed for Romano-British and Early Medieval skeletons. As discussed in the previous chapter, body proportions have the potential to inform bioarchaeologists about growth and development as well as stress experienced within these periods. Many of the indices and relative lengths of body segments demonstrates significant differences not just between females and males in their respective periods, but between the two periods. Females dating to the Romano-British period presented significantly different brachial and crural indices, skeletal torso height, relative lower limb length, relative upper limb length vs torso height, and relative torso height to the Early Medieval females. Generally, the Early Medieval females presented longer lower limb lengths and shorter skeletal torso heights compared to the Romano-British counterparts. Within the male samples, significant differences in the crural and brachiocrural indices, skeletal torso height, relative lower limb length, and relative torso height were present. Early Medieval males possessed greater lower limb and torso lengths than Romano-British males.

4. **Will there be differences between males and females with regards to stature and body proportion indicating differences in general health, nutritional resources, mobility, and response to climatic environment? What can this indicate about growth and development during these two periods?**

Differences between females and males were detected with regard to stature and a few body proportions. The increase in stature between the two periods was not equal for females and males. Females presented a slight increase in stature, which was determined to be statistically significant; however the standard errors of both regression equations used to calculate stature can account for the differences in mean stature between these two periods. For the males, a significant and unambiguous increase in stature occurred with the Early Medieval period. The increase in stature in males and small increase in stature for females produces a greater amount of sexual dimorphism, which according to Eveleth (1975) and Bharati (1989), indicates a healthier population as males are able to reach their genetic potential in stature. When stature calculated by the Fully anatomical method was compared to stature calculated using the population specific regression formulae, interesting patterns emerged. Those individuals whose stature was inaccurately estimated using the regression formulae were found to have different body proportions compared to mean values. Individuals who demonstrated a lower crural index tended to have stature overestimated, emphasizing the need to compare crural indices to the mean index for the reference population for the regression equations. A few individuals had crural indices that were within a standard deviation of the mean crural index, however their stature was still inaccurately estimated using these formulae. Upon closer examination, the torso lengths of these individuals were either much longer or shorter than the mean length of the sample. Stature that was overestimated due to shortened torso length could denote individuals who might not be local, or perhaps suggest possible stress experienced during adolescence, a period when growth in this region is rapid. The assessment of indices discovered higher crural and brachiocrural indices, along with greater relative lower limb length within the Early Medieval male sample. These higher indices and relative limb lengths present multiple lines of evidence of an increase in tibial length compared to other body proportions. Based on studies of living populations, an increase in tibial length within males tend to signal an improvement in access to nutritional resources, especially during critical growth periods during the development of skeletal tissues. Interestingly, the changes seen in body proportions between the two periods were slightly different for females and males. The increase in the lower limb and decrease in torso length altered the female body proportions, especially since only a slight increase in stature was detected overall. However, the increase in stature along with an increase in both lower limb and torso lengths of Early Medieval males led to changes in fewer body proportions than the female sample.

5. Is there a decrease in the prevalence of stress indicators between the Romano-British and Early Medieval periods, a trend that has been detected in previous studies (Klingle, 2012; Roberts and Cox, 2007; Schweich, 2005) throughout the south and eastern regions of England?

The comparison of skeletal indicators of stress between the Romano-British and Early Medieval samples found statistically significant differences in the prevalence of two stress indicators. The first, dental enamel hypoplasia, displayed greater frequencies within the Romano-British sample. This statistical significance remained when the total sample was separated into female and male groups. However, southern sites like the Roman Suburbs of Winchester and Early Medieval sites within the Hampshire and Kent regions did not demonstrate a significant drop in the frequency of DEH between periods. This was repeated in the Oxfordshire region, with the Romano-British site of QFM and the Early Medieval sites within Oxfordshire. The second stress indicator with a significant difference between periods was periosteal new bone formation on long bones, with a greater prevalence found within the Early Medieval sample, though overall far fewer people were affected. No significant difference was discovered between periods and the presence of cribra orbitalia or residual rickets.

6. **Are there any geographical and/or temporal trends in stature, body proportion, and sexual dimorphism between these periods?**

When assessing changes in stature in geographically similar regions, significant differences were discovered in both females and males. Romano-British females from the site of QFM were statistically shorter than females from the Early Medieval regions, specifically females from Oxfordshire sites demonstrated an increase in stature between periods. A similar connection could not be made between the males at these sites/regions. Interestingly, there was not a statistically significant increase in stature between the Romano-British sites of Roman London and Butt Road and those sites of the Eastern region from the Early Medieval period. Overall, statistically significant differences in stature occurred between females and males in both periods. Within the Romano-British period, no large differences in stature were found between the five Roman sites analysed, though all sites demonstrated higher values of sexual dimorphism than the Early Medieval sample. Similarly, no significant differences in stature between the Early Medieval sites/regions was discovered in female and male samples. The amount of sexual dimorphism in stature during the Early Medieval period was greater than that of the previous period. When assessing variation in different body proportions, interesting results were uncovered. A greater number of indices within the Romano-British sample presented sexual dimorphic traits. These include the brachial, intermembral, and brachiocrural indices as well as skeletal torso height, relative lower limb lengths, relative upper limb lengths vs torso height, and finally relative torso height. Interestingly, most Romano-British sites presented similar ratios, whereas greater variation between sites/regions was seen in the Early Medieval period. Definite changes in body proportions occurred through the transition between Roman rule and the Early Medieval period. Most notably, indices or relative ratios of elements involving the tibia showed differences within the male sample between these two periods. It has been demonstrated that growth of the tibia is most sensitive to environmental perturbations within males. Not only was there an increase in the crural index between the two periods (indicating a comparable increase in tibial length), but higher brachiocrural and intermembral indices seen in Romano-British males point to shortened tibial length compared to other long bones, pointing to improved life conditions.

7. **What potential information may be lost through the analysis of long bone lengths alone when assessing temporal trends in stature?**

Though there are inherent issues relating to stature estimation in human skeletal remains (incorrect body proportions and introduction of errors to name a few), this thesis has discovered that through the use of the revised Fully anatomical method, a wealth of information can be provided, not only with regard to stature estimation, but body proportions. As demonstrated previously, the use of long bone lengths alone when assessing stature or general health misses an important area of the body during growth and development, the torso. Skeletal markers of stress during growth and development occur prior to adolescence and this is the period during which the torso grows most rapidly. Adversity during adolescence, which impact final stature and relative torso height if adequate resources are not available. This period of outward maturation signals a threshold in both samples studied, especially for males. For example, Early Medieval males demonstrate a lower relative torso height value than the remains of the other three groups. Evidence of a threshold for Early Medieval males around the time of puberty, where they start taking on more adult roles in society, could impact their overall nutritional input/output affecting growth within the torso, thus affecting their relative torso height. This possibility would not have been discovered if long bone lengths alone were analysed, proving the importance of looking at the whole individual when possible.

8.3 Limitations:

Though this thesis provided an extensive examination of stature and body proportions from the Romano-British and Early Medieval periods in England, a number of limiting factors were apparent. The first limitation was time constraints with data collection, which meant that sex and age estimations were not assessed by the author and instead relied primarily on published and unpublished reports. Time constraint also impacted the amount of detailed recording of stress indicators presents, such as the recording of DEH by tooth to assess true prevalence rates. A factor that also limited the amount of interpretation regarding possible migration of individuals was the lack of isotope data for the sites analysed within this thesis. This limitation could not be helped, as those sites with corresponding isotope analysis were unavailable for analysis. Finally, as many cemetery populations had a range in preservation and taphonomic damage to skeletal element and the smaller number of inhumations located at various sites, could possibly lead to data bias within the results.

8.4 Future Directions

The detailed analysis of stature and body proportions from a transitional period in England brought forth new directions and avenues for future research. These avenues not only include continued analysis of Romano-British and Early Medieval populations, but involve the detailed analysis of different body proportions not currently utilized in bioarchaeology.

- To fully assess the growth and development of both periods, it would be necessary to analyse measurements of skeletal elements from non-survivors (non-adults) of the population along with the survivors (adults). In conjunction with these measurements, incremental isotopic analysis could provide insight to stress experienced during the growth period and differences seen between the non-survivors and survivors. The addition of isotopic analysis could aid in determining if variation in body proportions could identify stress experienced during childhood development.
- The possibility of identifying non-locals through the thorough analysis of individuals who possessed body proportions outside mean values. To conduct this research, enamel from dentition must be sampled for strontium and oxygen isotopes (and lead for the Roman period) to determine if those with unusual body proportions present values non-local to their burial place.
- To address the issue of not having any torso representation within regression formulae, a formula that includes the vertebral body heights of the lumbar vertebrae should be created. This may lead to an improved accuracy in the estimation of stature as it includes information about the trunk.

- Is there a relationship between shortened torso lengths seen in adults (as measured by vertebral body heights) and vertebral neural canal size that would be related to stress experienced during childhood (VNC) and adolescent (vertebral body height) development? To determine if there is a correlation between these two measurements in adults (survivors in past populations), a known human skeletal collection must be analysed.
- Measure lengths of the metacarpals and metatarsals and compare these measurements to long bone and torso lengths. These comparisons will aid in determining if the theory posited by Pomeroy *et al.* (2012) with regard to the thrifty phenotype hypothesis could be a possible indicator of stress experienced during growth and development. This theory hypothesizes that the body prioritizes growth in certain areas of the body during periods of stress; the most important of which is the brain (cranium). It also proposes that priority is given to growth of the hands and feet over growth of the long bones. If possible, utilizing a known skeletal collection to examine if this relationship can be observed in skeletal populations could add another skeletal indicator of stress.
- Greater examination of the skeletal elements of the spinal column is needed with regard to the development of vertebral sections, which areas of the trunk grow fastest, and how might stress impact the skeletal growth. It would also be interesting to determine if there sexual differences in the vertebral regions as well as variation across periods, geography, etc.

Chapter Nine: Bibliography

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Appendices

Please see Flash Drive for Appendices 1-5

Appendix 1: Summary statistics on the sex and age distribution of the Romano-British and Early Medieval sample analysed

Appendix 2: Summary statistics on the prevalence of stress indicators within the Romano-British and Early Medieval sample analysed. Results from multiple chi-square tests are also present

Appendix 3: Statistical comparisons of methods for calculating missing vertebral elements and section, linear regression graphs for all population specific formulae, statistical comparison between Fully anatomical stature and frequently cited mathematical regressions, and mean PPE for all equations examined are presented within this appendix

Appendix 4: Summary statistics for long bone measurements and indices between age categories and sites.

Appendix 5: Lists of all the sites analysed including location, dates, and number of inhumations recovered from each cemetery; description of measurements taken throughout analysis; list of museums and institutions visited and contact details.